STRESS CONCENTRATION IN A BEAM WITH A REINFORCED ELLIPTICAL DISCONTINUITY

BY

TERRIL ALEXANDER EFIRD
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Cambridge, Massachusetts
May 19, 1950

Professor Joseph S. Newell
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

I, Terril A. Efird, in accordance with the requirements for the degree of Naval Engineer, and I, A. Homer Skinner, Jr., in accordance with the requirements for the degree of Master of Science in Naval Architecture, submit herewith a thesis entitled "STRESS CONCENTRATION IN A BEAM WITH A REINFORCED ELLIPTICAL DISCONTINUITY."

Respectfully,

STRESS CONCENTRATION IN A BEAM

WITH A REINFORCED ELLIPTICAL DISCONTINUITY

BY

TERRIL ALEXANDER EFIRD
Lieutenant, U. S. Navy
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Submitted in Partial Fulfillment of the

Requirements for the Degrees

of

NAVAL ENGINEER AND MASTER OF SCIENCE IN NAVAL ARCHITECTURE

Respectively

at the

Massachusetts Institute of Technology

ACKNOWLEDGEMENT

The authors wish to express their appreciation for the advice given by Professor C. H. Norris of the Department of Civil Engineering and by Professor W. M. Murray of the Department of Mechanical Engineering in the conduct of the research and in the analysis of the results.

To Mr. W. L. Walsh are due thanks for his invaluable aid in performing the stresscoat tests. Professor W. S. Bailey's instruction and assistance in performing the tensile tests and in the use of the Riehle Testing Machine were greatly appreciated.

To the Boston Naval Shipyard the authors are indebted for the fabrication of the steel model.

The suggestions and criticisms of Professor J. H. Evans were of great help in the preparation of the report.

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I

SUMMARY

This report investigates experimentally the stresses occurring around one quadrant of a centrally-located reinforced elliptical discontinuity in a steel I beam subjected to pure and complex bending. The reinforcement, in the form of a flat bar ring, is varied from an excess breadth to as small a breadth as possible at a constant thickness approximately equal to that of the web. For each reinforcement the beam was tested in pure bending and at three ratios of average shear stress to maximum bending stress at the section of the opening as calculated for the intact beam. The stresses at seventeen selected points in the web, reinforcement and flanges were derived from strains observed from Baldwin SR-4 electrical strain gages in conjunction with "stresscoat" diagrams. Stress concentrations are expressed by the stress concentration factor, defined as the ratio of the observed stress at any point to the calculated principal stress at the point in the intact beam.

The principal results are

1. Stress concentrations of considerable magnitude do exist in the reinforcing ring and in the web adjacent to the discontinuity.

2. Stress concentration factors in the web at the neutral axis are large and vary directly with breadth of ring and inversely with ratio of shear stress to bending stress.

3. Stress concentration factors in the reinforcing ring vary directly with ratio of shear to bending stress and inversely with breadth of ring. They are little affected by breadth of ring below breadths of 7 times the web thickness, where the factor has a value of 1.61, but show a rapid increase as breadth of ring is decreased further.

4. For the dimensions of elliptical opening tested (minor axis equal to 0.4 depth of beam, major axis equal to 1.5 minor axis before reinforcement added), stresses in the flanges are little affected by the opening, reinforced or unreinforced.

5. The greatest observed value of the stress concentration factor, 3.04, occurred in the web at the neutral axis.

6. It was found that increased shear caused a marked increase in the values of the stress concentration factor in the reinforcing ring over those for pure bending, with the result that yielding would take place first in the ring.

The recommendation is made that the breadth of reinforcing rings around elliptical openings in beam webs be made not less than 7 times the thickness of the web, where the ring thickness is the same as that of the web.

II

INTRODUCTION

Discontinuities, either for the purpose of weight reduction or access, occur frequently in such ship structural members as floors, frames, deck beams and longitudinals. In practically every instance the member is loaded as a beam in complex bending, i. e. with the presence of both shear and bending. In the case of longitudinals, axial tensile and compressive forces are also present. It has long been recognized that stress concentrations exist around discontinuities in plates and as a plate is more readily subjected to mathematical analysis, several theoretical solutions have been made. In recent years, various investigators have given thought to the problem of the beam, making use of the analysis of the plate.

That the effect of peripheral reinforcement about a discontinuity was to reduce the stress was shown photoelastically by Ruffner and Schmidt (1)* for reinforced and non-reinforced centrally-located web cut-outs in a beam subjected to both shear and bending. Timoshenko (2) made an approximate solution of the stress distribution in a plate with a circular opening, reinforced by a face plate or bead of welding, subjected to uniform tension. He found that the cross section of the bead

*Numbers in parentheses indicate references in the Bibliography.

was the determining factor and that the larger the cross section of the bead, the smaller the stress concentration became. A bead in the form of two angle bars gave the same results as a bead consisting of a flat plate alone.

Sezawa and Kubo (3), conducting their investigations with the use of gelatine models with reinforced circular openings under tension, found that there was a stiffening ring width beyond which, if it were increased, no further reduction in the stress concentration was obtained. Experiments made by Ballinger and Obermeyer (5) of the tensile stress distribution around a reinforced ovaloid opening (consisting of two semi-circles joined by a parellel section) indicated the presence of concentrations at the juncture of the circular arcs and the parellel section.

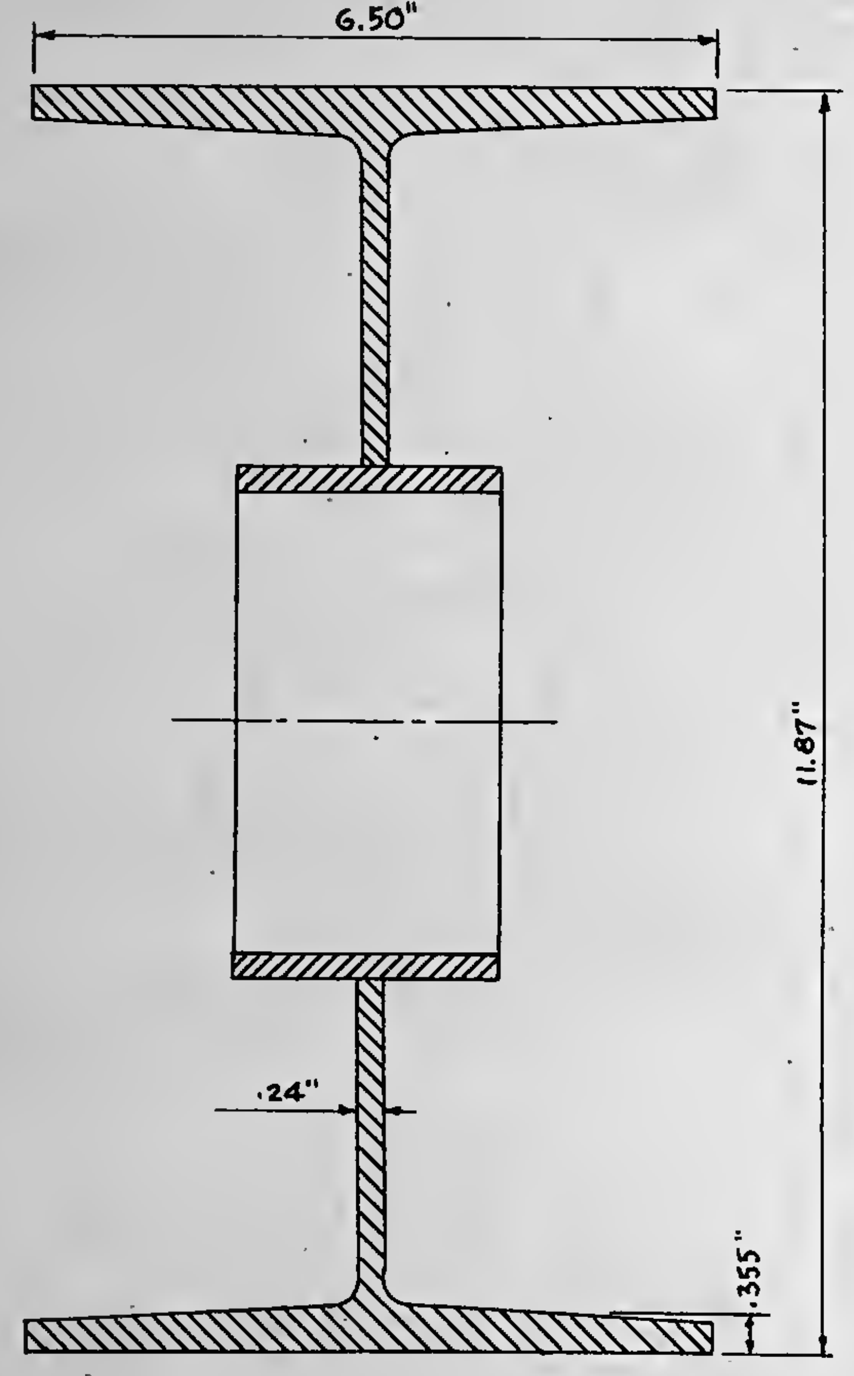
A theoretical solution for an ovaloid opening in the web of a beam subjected to pure bending was obtained by Joseph and Brock (6). Their results are shown by the dashed line in Figure VII.

A theory of notch stress, developed by Neuber (7), gives a solution for a small elliptical hole in a bar subjected to complex bending, the axis of the bar being parallel to the major axis of the ellipse. With an elongated ellipse of small dimensions relative to the width of the bar, he states that the increase of local stress is essentially due to the presence of shear.

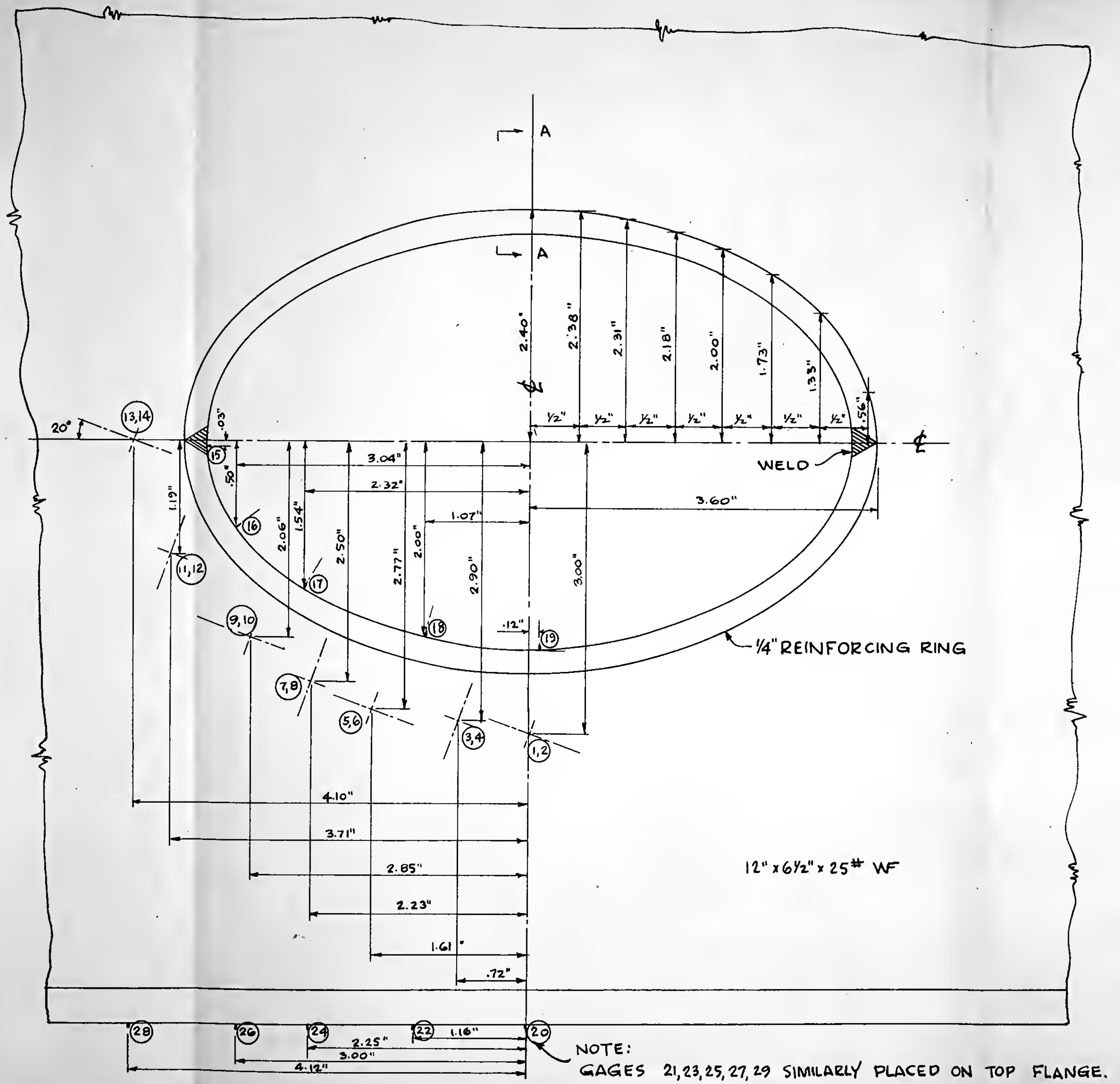
Since the majority of previous investigators of this subject have dealt only with the conditions of uniform tension or pure bending, which are only approximations to the actual loading encountered by the structural member in a ship, the subject selected for the present study is a beam having a central elliptical discontinuity of variable reinforcement loaded in complex bending, (Figure I). The elliptical shape was chosen for the purpose of comparing its concentrations with those of the ovaloid. The reinforcement was varied from an excess amount to as small a value as practicable in order to ascertain whether the results of Sezawa and Kubo (3) would hold for complex bending. To indicate the relative degree of shear and bending for any particular condition of loading, the parameter τ/σ, the ratio of the nominal shear stress to the maximum bending stress at the section, is used. τ is here defined as the shear at the section divided by the product of the depth of the beam by the thickness of the web. σ_1 represents the bending stress at the extreme fibre. For the calculation of these ratios, the intact beam is used.

The application of the electrical wire strain gages to an eleven foot steel model was deemed the most expedient method of attaining the desired results for this three-dimensional problem. The thickness of the reinforcement was held constant while the breadth was reduced in five successive steps to the least possible amount allowed by the presence of the gages themselves. For all tests the beam was simply supported in

the Riehle 100,000 Pound Testing Machine shown in Figures III - VI. Strain measurements under the loading conditions shown in Figure II were made on the surface of the stiffening ring, on both sides of the adjacent web, and on the flanges by gages located as in Figure I. Stress concentration factors were obtained for each gage location.

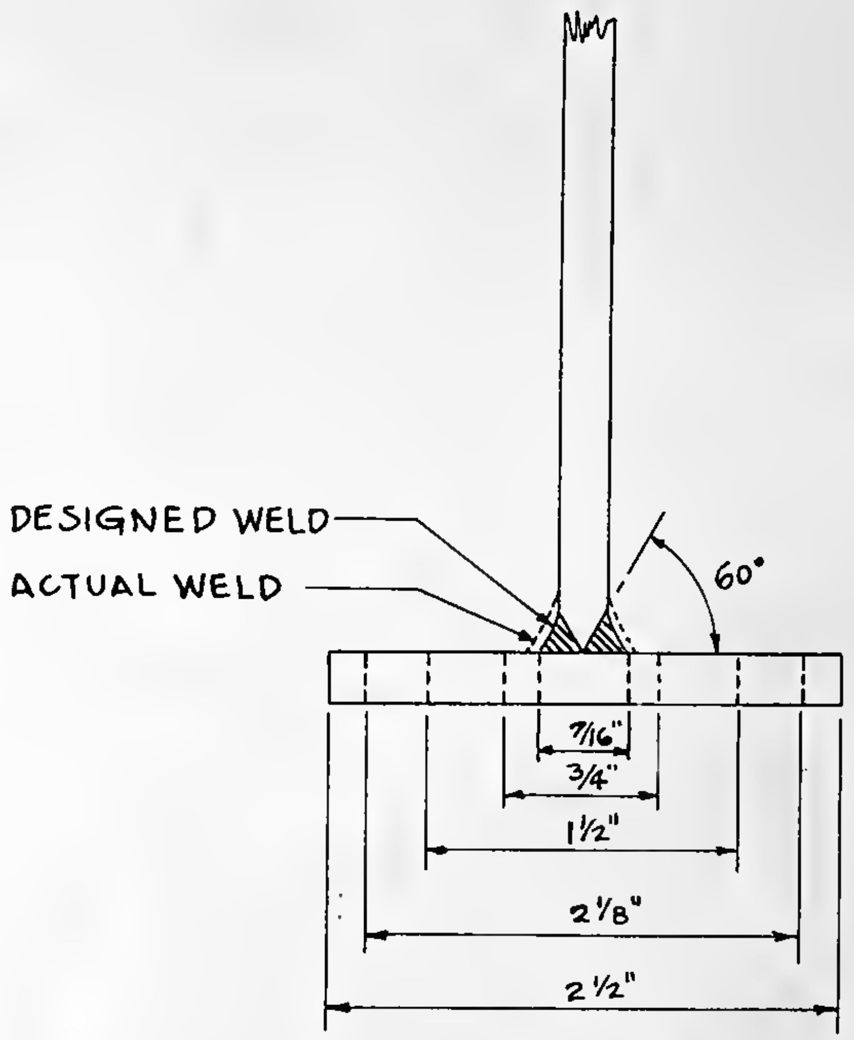


SECTION
6" = 1'-0"



GENERAL NOTES -

1. GAGES NOS. 1 THROUGH 14 LIE ON THE SURFACE OF THE WEB, ODD NUMBERS ON ONE SIDE, EVEN NUMBERS ON THE OTHER.
2. GAGES NOS. 15 THROUGH 29 LIE IN THE LOCATIONS SHOWN IN THE VERTICAL CENTERLINE PLANE OF THE BEAM.
3. ALL GAGES BALDWIN SR-4 TYPE A-8.



SECTION
"A - A"
SHOWING WIDTHS OF REINFORCING RING TESTED

FIGURE I

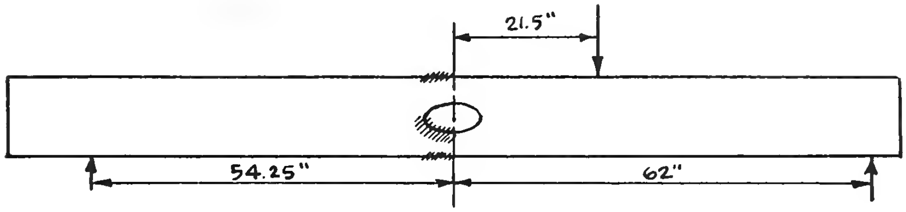
PLATE I

A.N.
D.A.B.

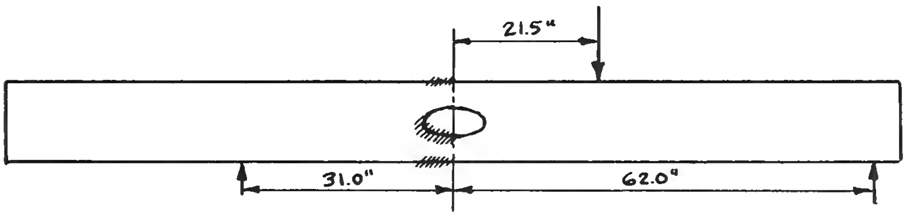
APRIL 24, 1950

LOCATION OF GAGES

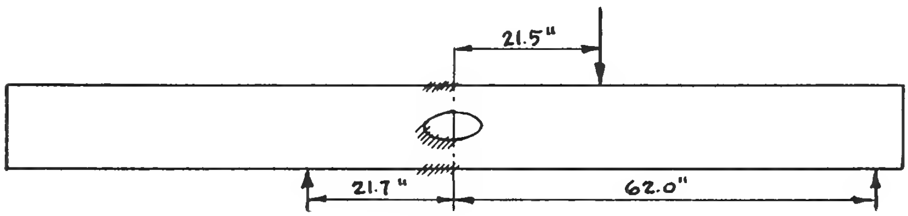
Figure II



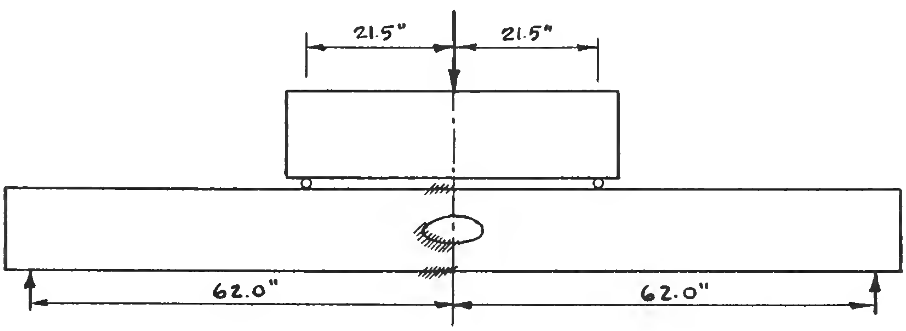
$\frac{\tau}{\sigma} = .20$



$\frac{\tau}{\sigma} = .35$



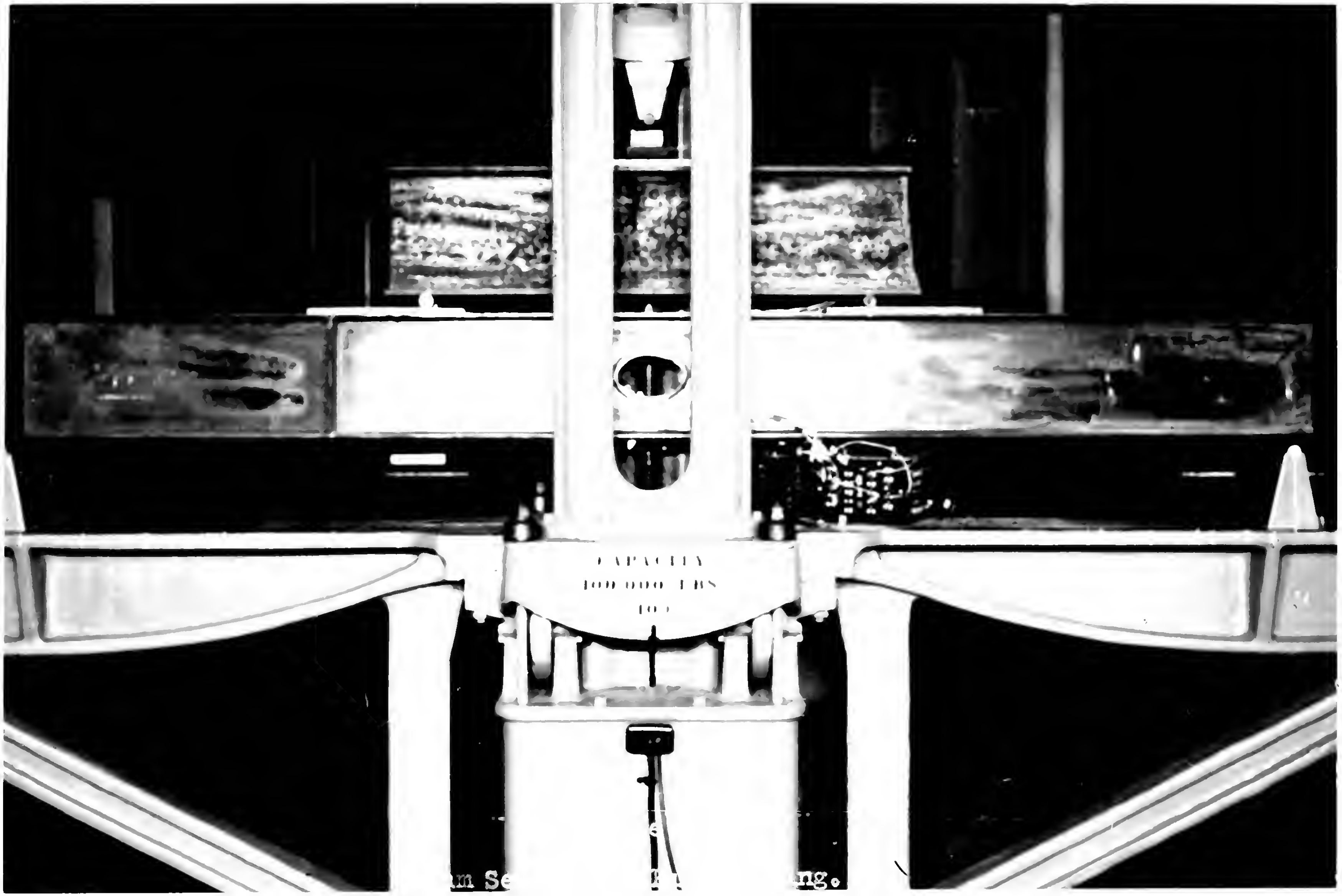
$\frac{\tau}{\sigma} = .50$



PURE BENDING

APRIL 26, 1950
A.N.S.
J.Q.E.

LOADING DIAGRAM
AREA STUDIED SHOWN SHADED


CAPACITY
100 000 LBS

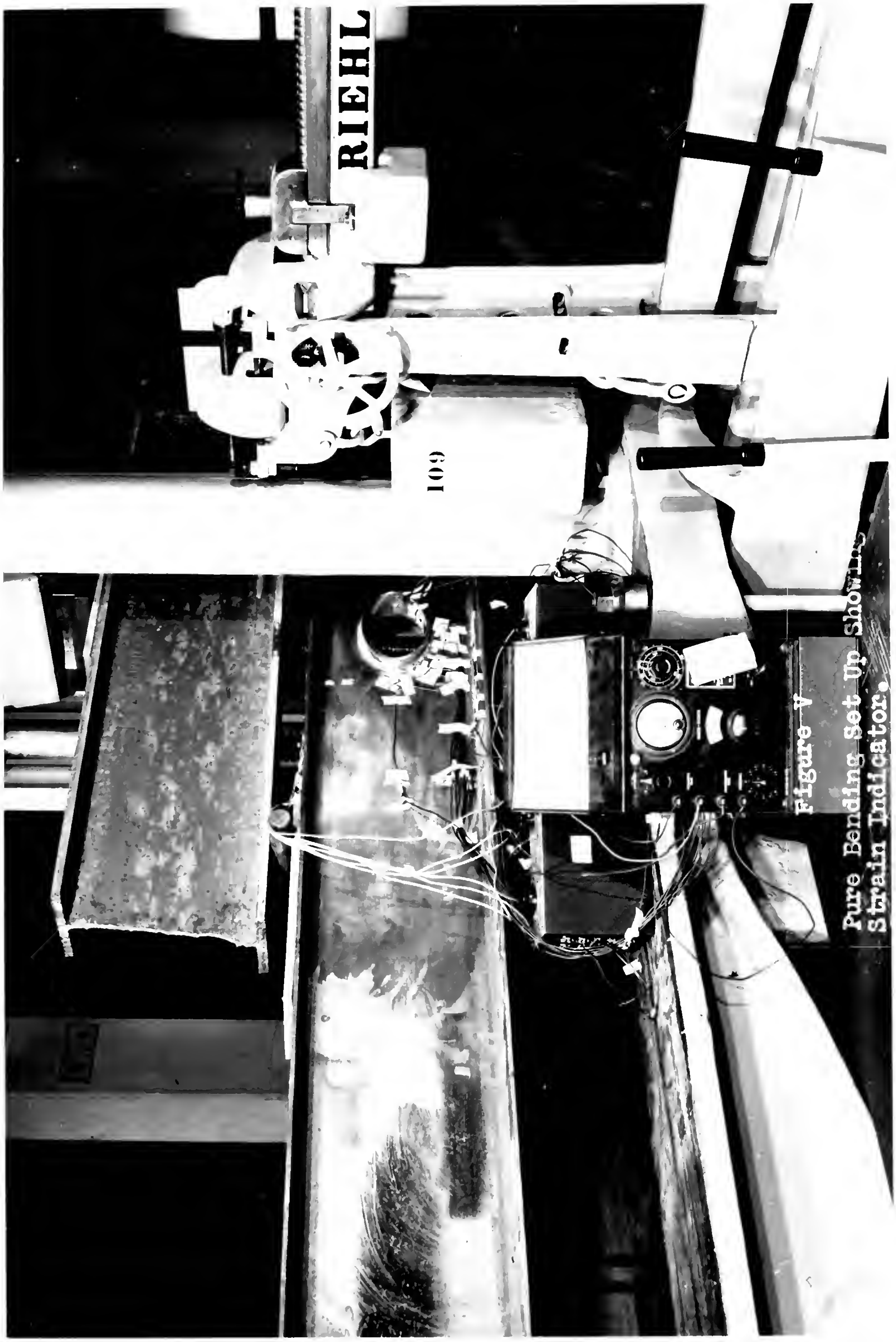


Figure V
Pure Bending Set Up Showing
Strain Indicator.

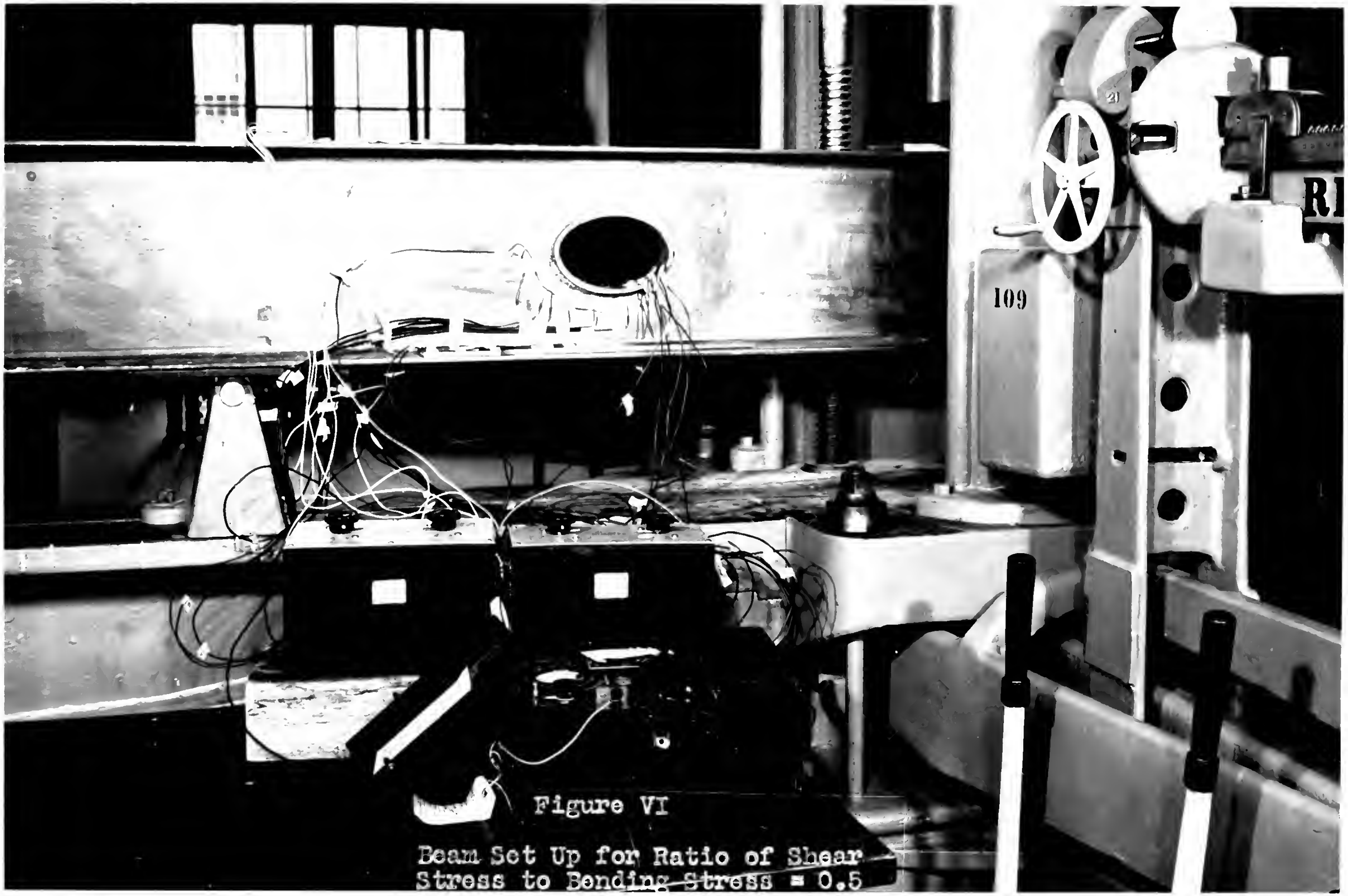


Figure VI

Beam Set Up for Ratio of Shear Stress to Bending Stress = 0.5

III

PROCEDURE*

A suitable beam was selected, which, due to its modulus and length and by variation in the location of supports and load, would produce ratios of nominal shear stress to bending stress (τ/σ) between 0.2 and 0.5 at the center of the section to be investigated. Ratios of shear stress to bending stress of 0.2, 0.35, and 0.5, as well as pure bending, were chosen as one of the parameters of the investigation. The second parameter was the variation in width of the flat bar stiffening ring installed as shown in Figure I. Five widths of stiffening ring were tested.

The beam used for the test was a 12" x 6½" x 25# wide flange high tensile steel beam eleven feet long. The high tensile steel permitted greater loads to be applied to the beam and consequently produced greater strains, thus tending to reduce errors in strain measurement.

The ¼" x 2½" mild steel flat bar stiffening ring was welded into the elliptical hole in which the ratio of depth to length was 1.5. The depth of the hole before installation of the stiffening ring was 0.4 times the depth of the beam. After all welding was completed on the

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*Details of procedure are given in Appendix A.

beam, it was stress relieved by being heated up to 1125°F, held at that temperature for 1 hour, and allowed to cool in the furnace.

Standard flat plate tensile specimens were made to determine the modulus of elasticity of the beam and the stiffening ring.

Since the strains induced in the section under investigation were to be measured by Baldwin SR-4 Strain Gages, it was essential to determine their proper location and orientation in order that the most information be obtained with the least number of gages. A series of stress coat tests were performed to gain this information and are recorded in Figures XV through XVII. Stress coat is a brittle coating which cracks along lines normal to the principal tensile strains.

Type A-8 strain gages were used throughout the test because of their small size and short gage length (1/8 inch). This was necessary in order to obtain a number of strain readings in the web adjacent to the stiffening ring where space was limited, and, in the stiffening ring itself.

The strain gages were cemented to the beam and allowed to dry for a week before being used. Gage locations and orientation are shown in Figure I.

The strain gages were connected as shown in Figure XLII with one compensating gage used in conjunction with all the active gages to take account of temperature effects. Switching from one active gage to the other was accomplished by using two Baldwin 20 point switching units. Strains were measured directly in micro-inches per inch with a Baldwin Portable Strain Indicator, Model K.

For each stiffening ring width the beam was loaded successively as shown in Figure II by the Riehle 100,000 pound testing machine pictured in Figures III thru VI. The three tests for ratios of shear stress to bending stress plus the pure bending test gave four points to be used in plotting the results of the tests. For each loading condition, the zero reading was taken for each gage, then the load applied in four increments to the maximum load, and then reduced by the same increments. Strain readings were recorded for each increment of load increasing and decreasing as well as the initial and final zero readings in order to check the reliability of the gages.

The stiffening ring width was reduced by clamping the beam, with the web horizontal, in a shaper, then cutting transversely across the ring from one side to the other. This method proved very effective, since the rate of cutting was slow enough that the heat generated was insufficient to adversely affect the installed strain gages.

The stiffening ring was reduced in successive steps to 7/16" which was as narrow as it could be made without risking damage to gages installed on the stiffening ring and on the web.

After completion of all tests, the web gages were removed and another stress coat test was made for a shear stress to bending stress ratio = 0.5 in order to determine how nearly the strain cracks conformed to those originally obtained with the stiffening ring width $2\frac{1}{2}$ inches. These results are shown in Figure XVIII and are superimposed for comparison on the original data as shown in Figure XV.

The stress concentration factors determined in this experiment are obtained by dividing the experimental value of stress by the calculated principal stress at the same point in the intact beam.

IV

RESULTS

The results of this investigation are embodied in Tables I-V, inclusive; Figures VII to XIV-D, inclusive; and Figures XV-XVIII, inclusive.

Tables I-V give the value of the principal stress derived from the observed strains for every gage location and each condition of loading. These are compared with the calculated principal stress for the same point by means of the stress concentration factor, which is defined as the ratio of the derived stress for the beam with the reinforced discontinuity to the calculated stress for the intact beam.

Figures VII to XIV-D are graphical representations of the results incorporated in Tables I-V, and show the variation of stress concentration with the two basic parameters: (1) breadth of stiffening ring, and (2) ratio of the nominal shear stress to the maximum bending stress (τ/σ) taken at a section coincident with the vertical centerline if the ellipse, for the intact beam, Nominal shear stress is defined as the shear force at the section divided by the product of the depth of the beam times the thickness of the web. For the stiffening ring, results are first presented, in Figures VIII, IX, and X, by graphs of stress concentration factor as a function of distance along the elliptical arc of the stiffening

ring surface measured from the vertical centerline. Figures XI and XII, which are the cross curves of Figures VIII, IX, and X, show the variation of the factor with the two basic parameters. For the web, the value of the factor as found in Tables I-V for gages 13 and 14 is plotted against the two basic parameters. These gages were selected because only minor stress concentrations were found to be present at all other web gage locations, except for the smallest breadths of stiffening ring.

Figures XV, XVI, and XVII, in Appendix D, show the lines of the cracks in the stress coat for load conditions $\tau/\sigma = 0.20$, 0.50, and pure bending. From these diagrams, θ, the angle between the axis of the gage and the principal tensile strain (the orthoronal trajectories of the crack lines), was determined. The values of θ for $\tau/\sigma = 0.35$ were obtained from those for 0.20 and 0.50 by linear interpolation.

Figure VII

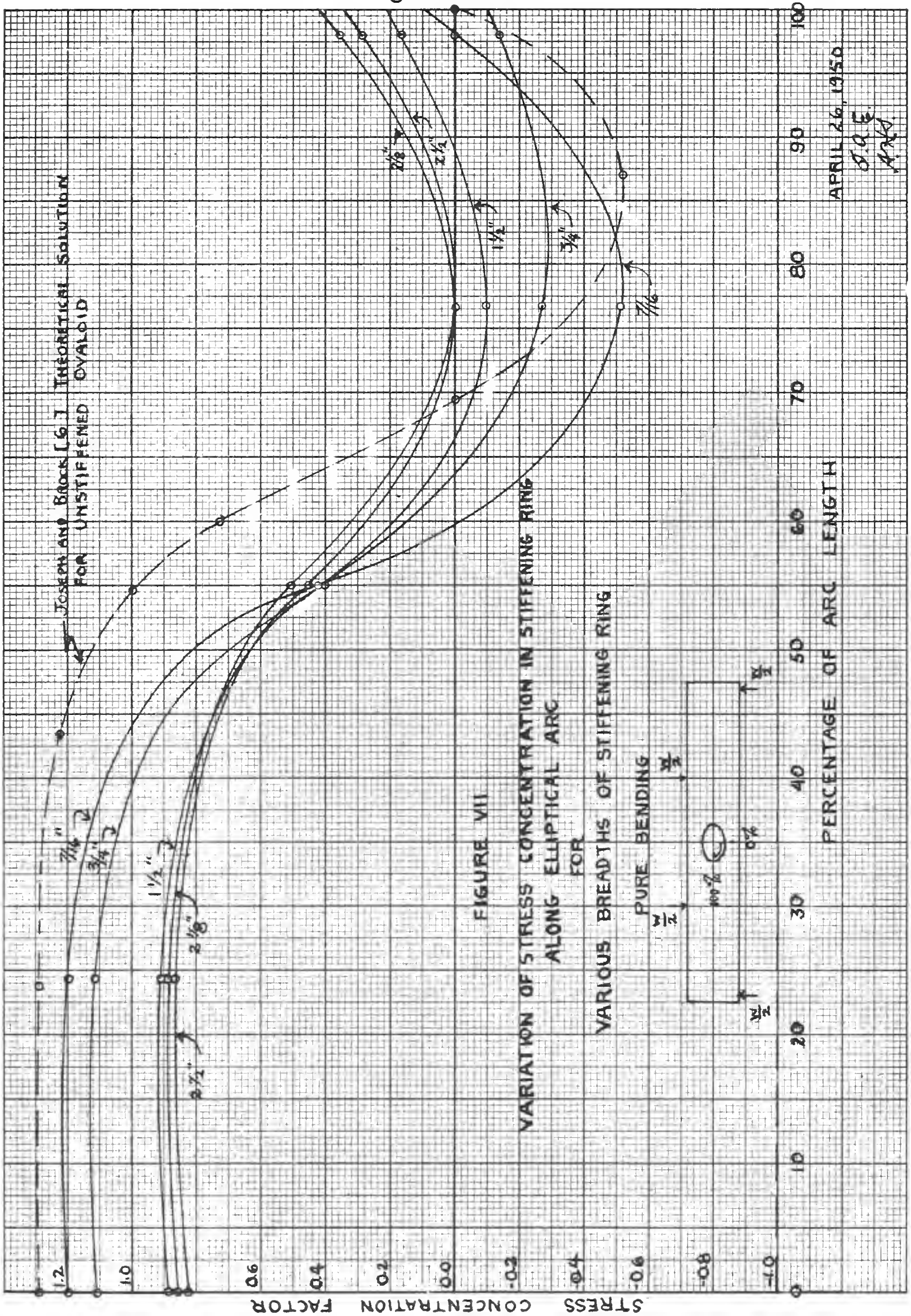

JOSEPH AND BROCK [6] THEORETICAL SOLUTION
FOR UNSTIFFENED OVALOID
FIGURE VII
VARIATION OF STRESS CONCENTRATION IN STIFFENING RING
ALONG ELLIPTICAL ARC
FOR
VARIOUS BREADTHS OF STIFFENING RING
PURE BENDING
PERCENTAGE OF ARC LENGTH
STRESS CONCENTRATION FACTOR
APRIL 26, 1950

Figure VIII

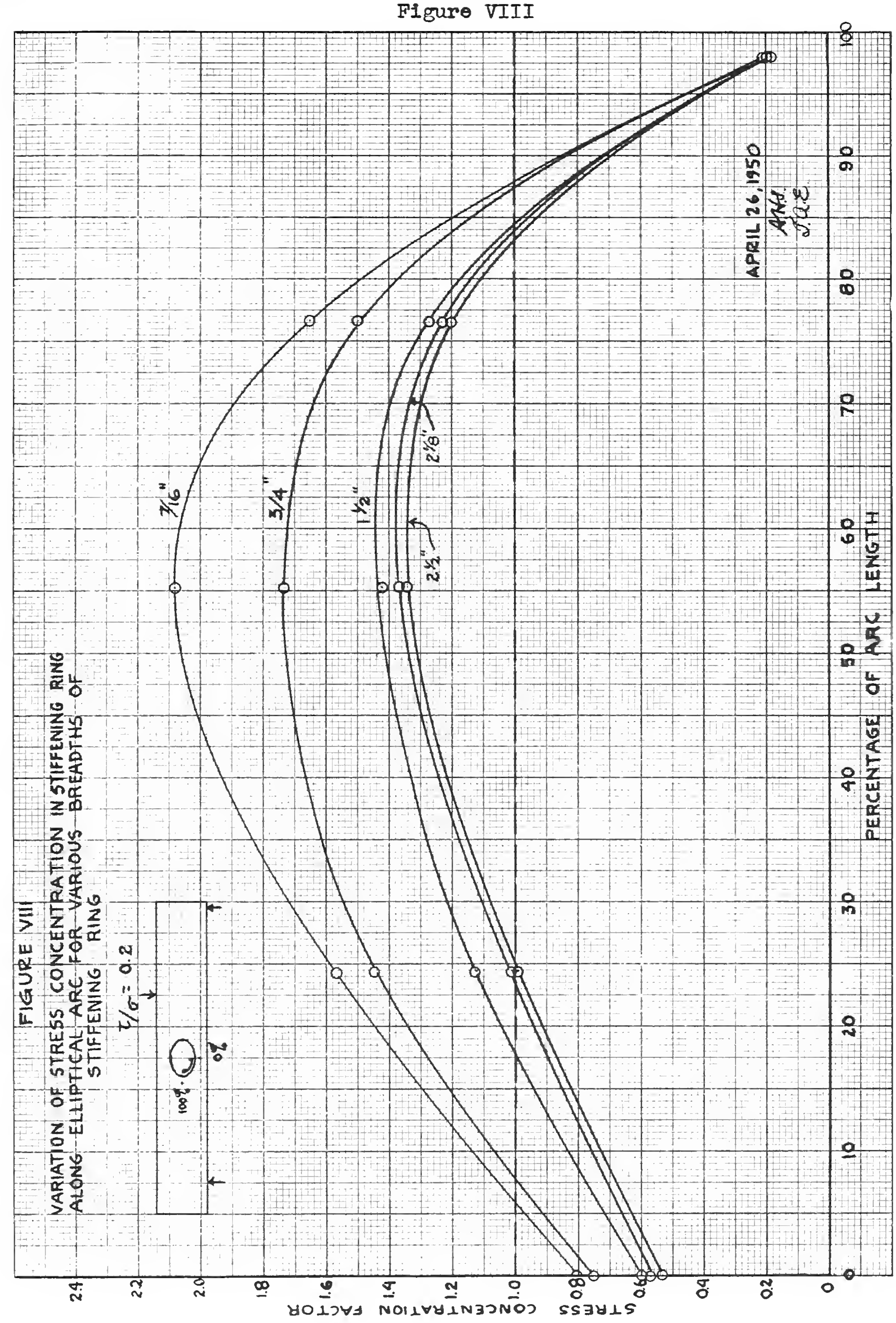


FIGURE VIII
VARIATION OF STRESS CONCENTRATION IN STIFFENING RING ALONG ELLIPTICAL ARC FOR VARIOUS BREADTHS OF STIFFENING RING
$\tau/\sigma = 0.2$
100%
0%
7/16"
3/4"
1 1/2"
2 1/8"
2 1/2"
APRIL 26, 1950
STRESS CONCENTRATION FACTOR
PERCENTAGE OF ARC LENGTH
0
10
20
30
40
50
60
70
80
90
100
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

Figure IX

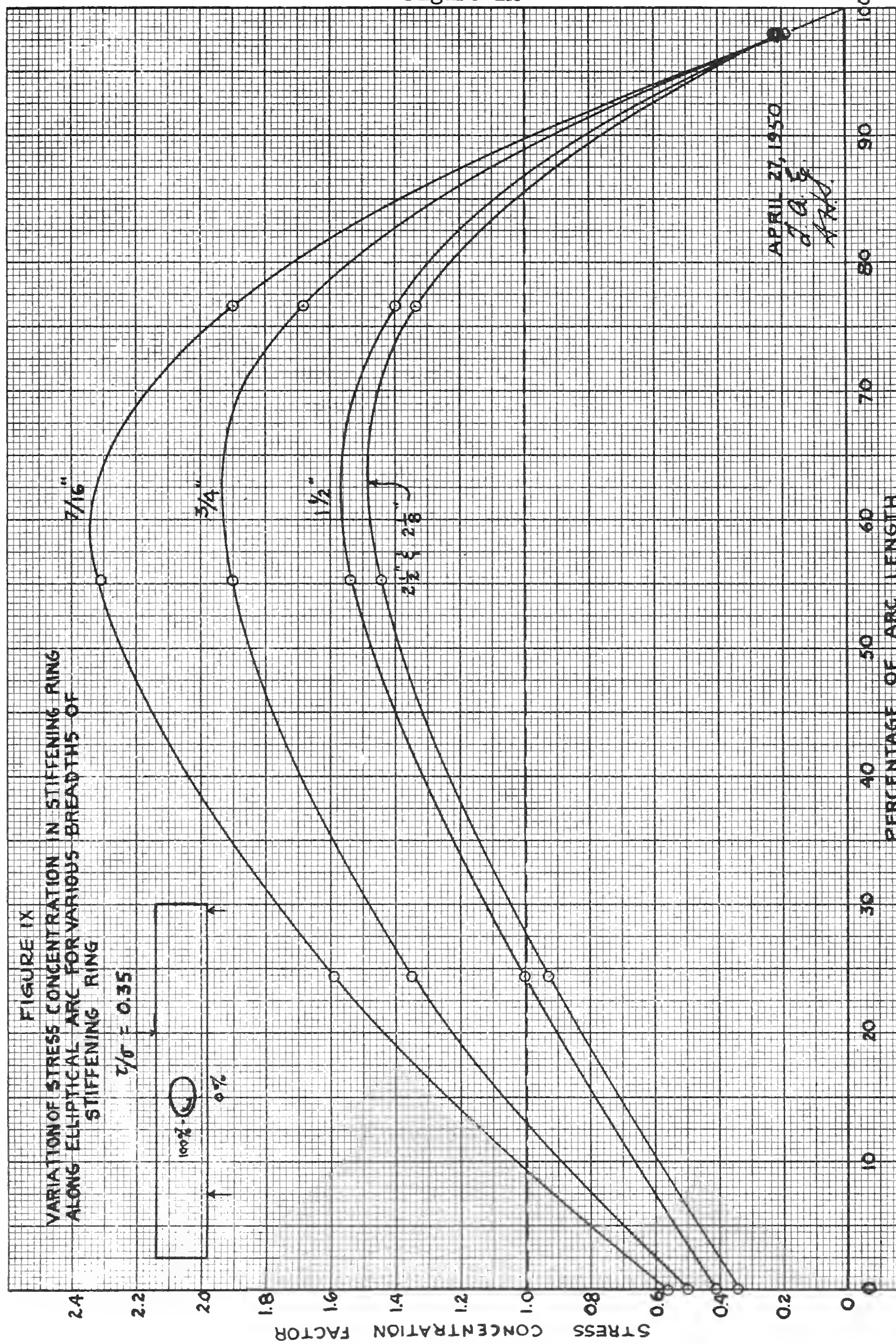


FIGURE IX
VARIATION OF STRESS CONCENTRATION IN STIFFENING RING ALONG ELLIPTICAL ARC FOR VARIOUS BREADTHS OF STIFFENING RING
τ/σ = 0.35
100%
0%
7/16"
3/4"
1½"
2½" & 2⅞"
APRIL 27, 1950
PERCENTAGE OF ARC LENGTH
0
10
20
30
40
50
60
70
80
90
100
STRESS CONCENTRATION FACTOR
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

Figure X

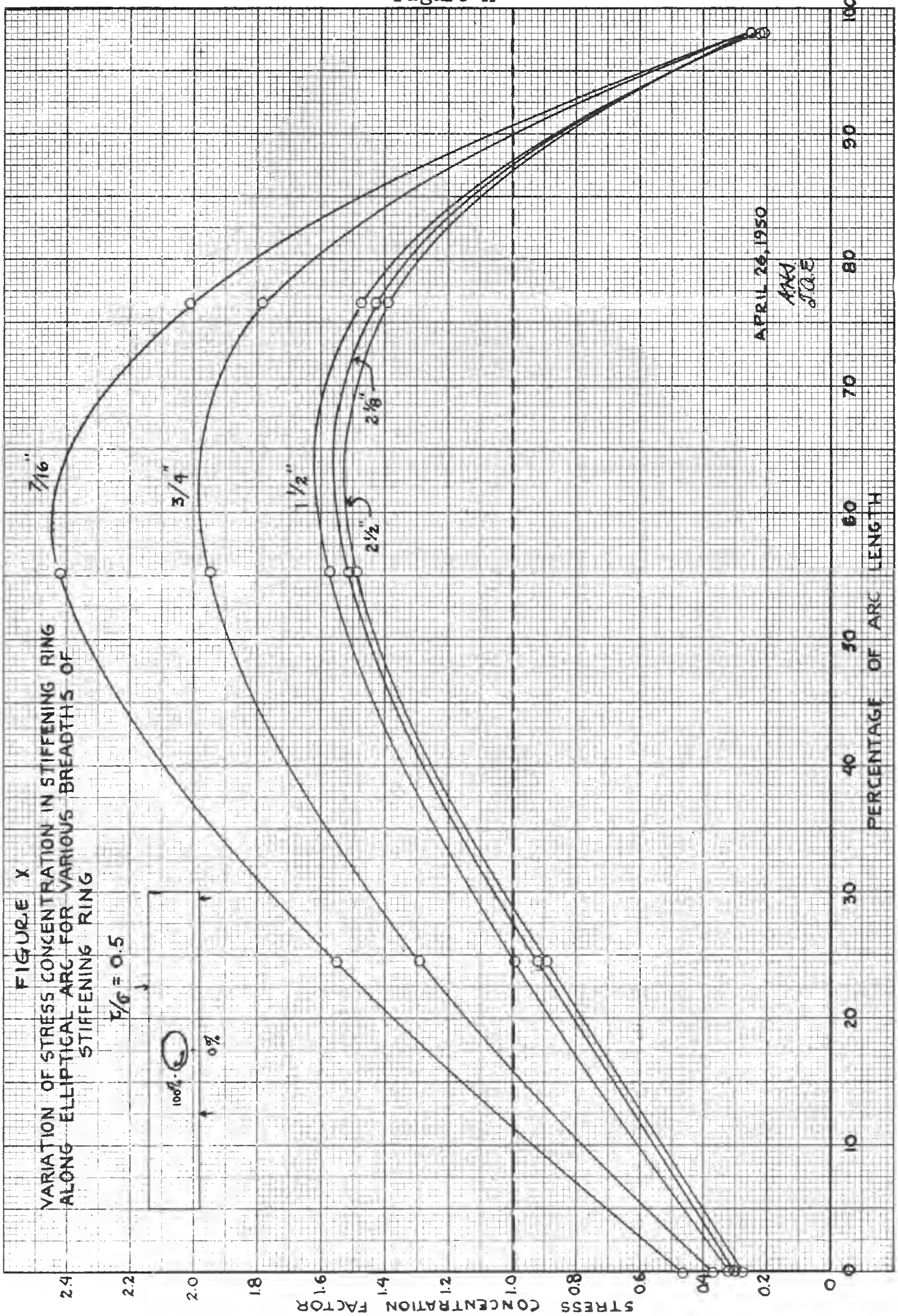


FIGURE X
VARIATION OF STRESS CONCENTRATION IN STIFFENING RING ALONG ELLIPTICAL ARC FOR VARIOUS BREADTHS OF STIFFENING RING
t/c = 0.5
100%
0%
7/16"
3/4"
1 1/2"
2 1/2"
2 1/8"
APRIL 26, 1950
STRESS CONCENTRATION FACTOR
PERCENTAGE OF ARC LENGTH

Figure XI

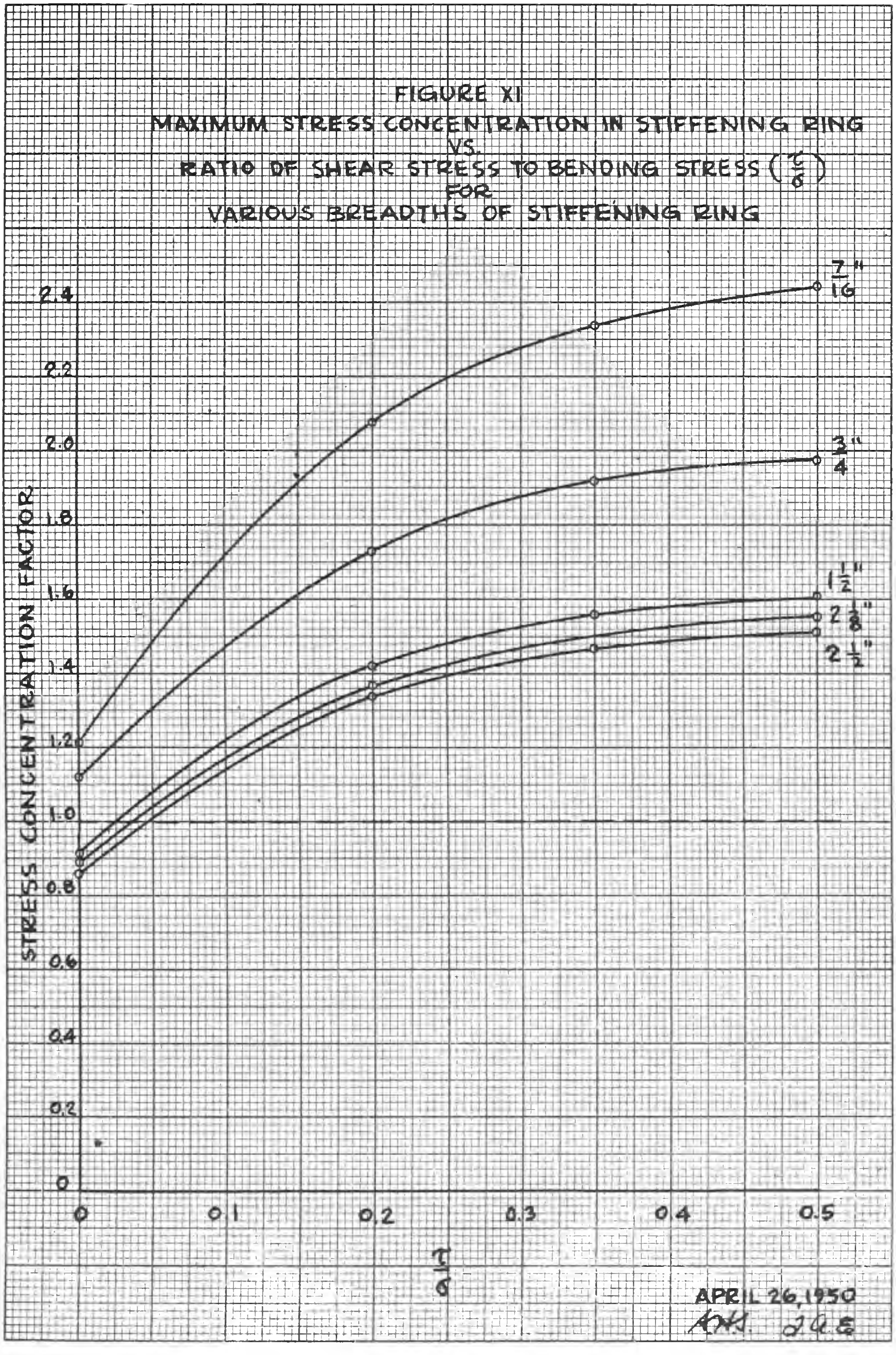


FIGURE XI
MAXIMUM STRESS CONCENTRATION IN STIFFENING RING
VS.
RATIO OF SHEAR STRESS TO BENDING STRESS ($\frac{\tau}{\sigma}$)
FOR
VARIOUS BREADTHS OF STIFFENING RING
STRESS CONCENTRATION FACTOR
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
$\frac{\tau}{\sigma}$
$\frac{7}{16}$"
$\frac{3}{4}$"
$1\frac{1}{2}$"
$2\frac{1}{8}$"
$2\frac{1}{2}$"
APRIL 26, 1950

Figure XII

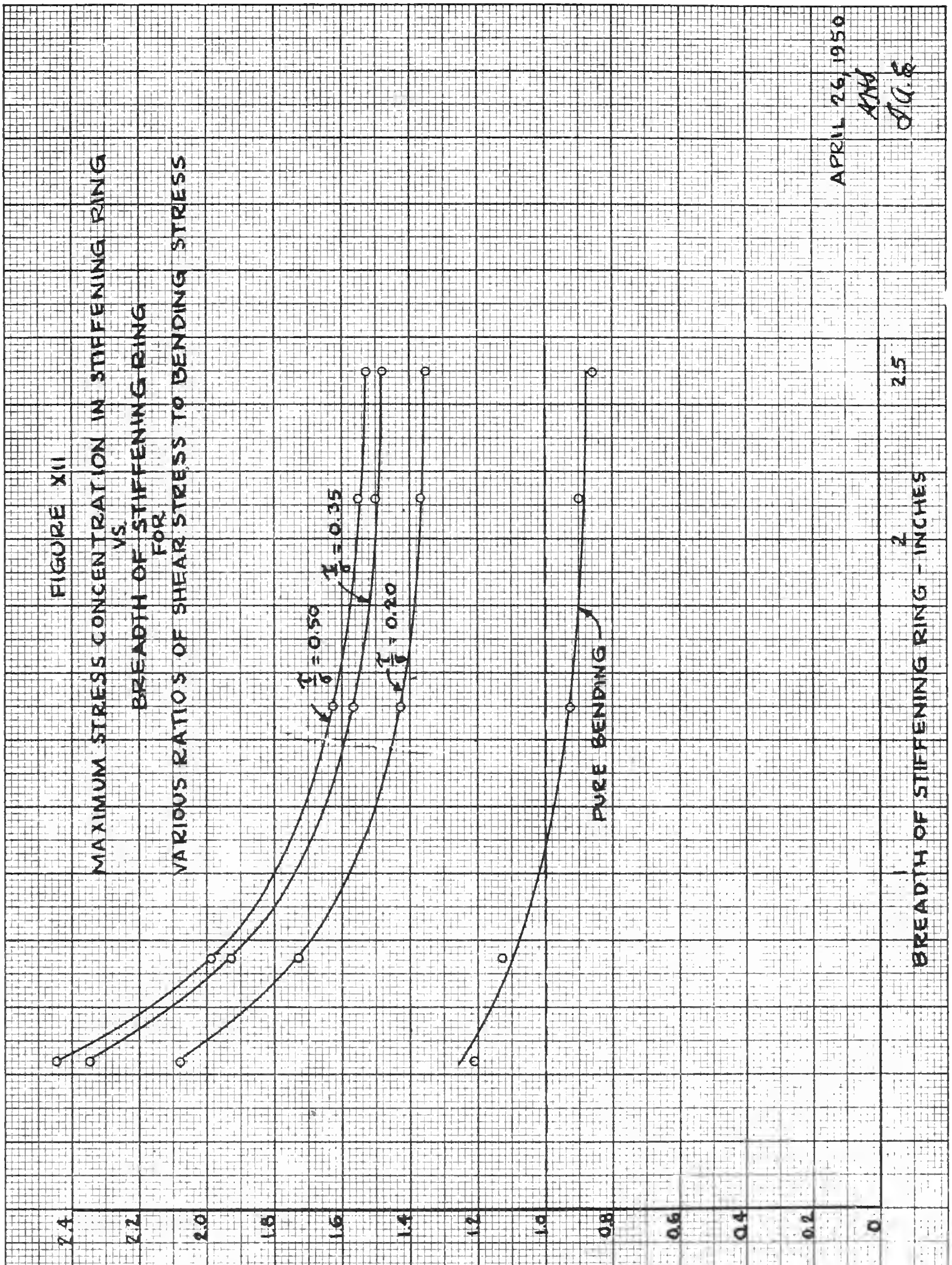


FIGURE XII
MAXIMUM STRESS CONCENTRATION IN STIFFENING RING
VS.
BREADTH OF STIFFENING RING
FOR
VARIOUS RATIOS OF SHEAR STRESS TO BENDING STRESS
τ/σ = 0.50
τ/σ = 0.35
τ/σ = 0.20
PURE BENDING
APRIL 26, 1950
STRESS CONCENTRATION FACTOR
BREADTH OF STIFFENING RING - INCHES

Figure XIII

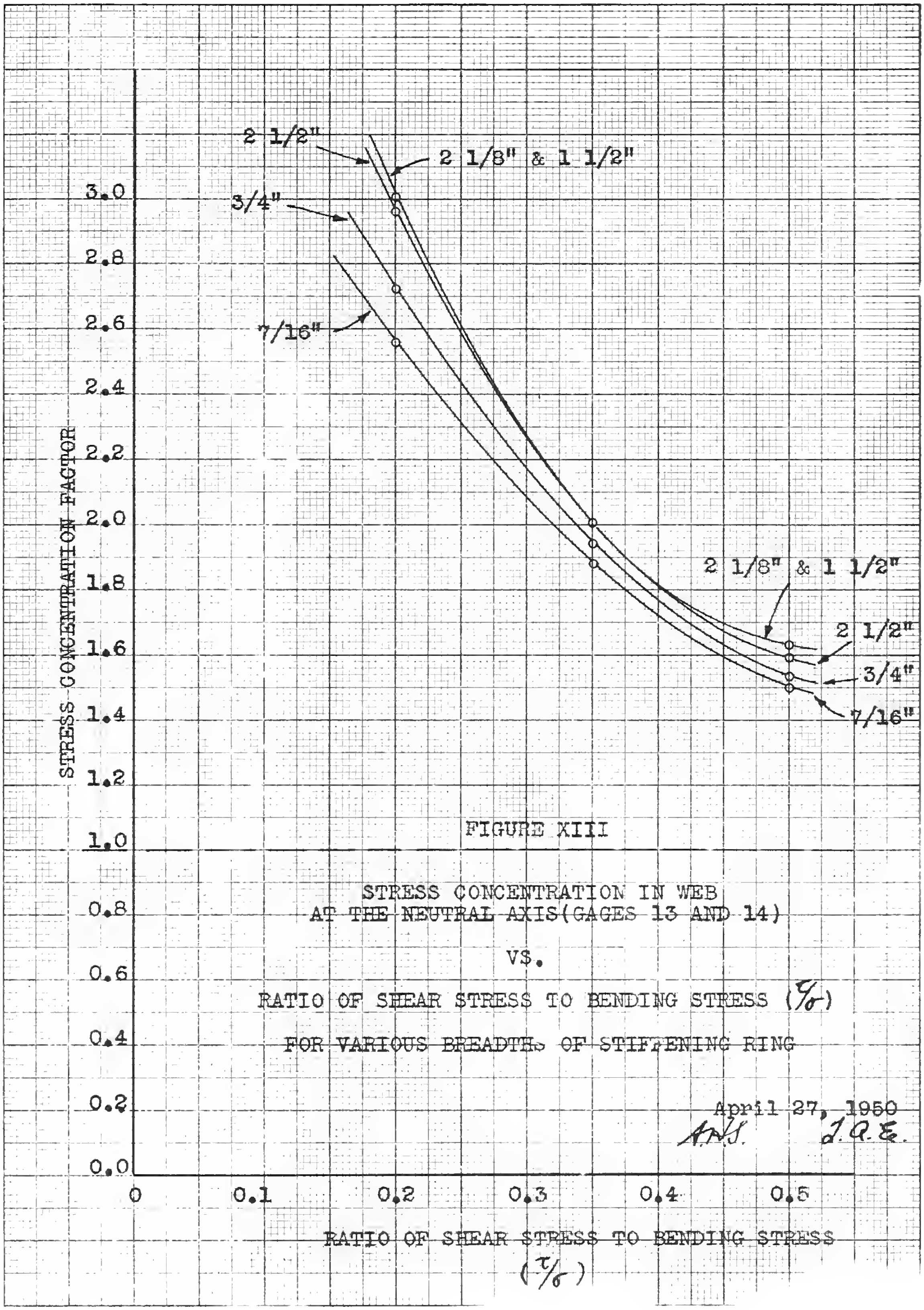


FIGURE XIII

STRESS CONCENTRATION IN WEB
AT THE NEUTRAL AXIS(GAGES 13 AND 14)

VS.

RATIO OF SHEAR STRESS TO BENDING STRESS (τ/σ)

FOR VARIOUS BREADTHS OF STIFFENING RING

April 27, 1950

A.N.S. J.Q.E.

Figure XIV

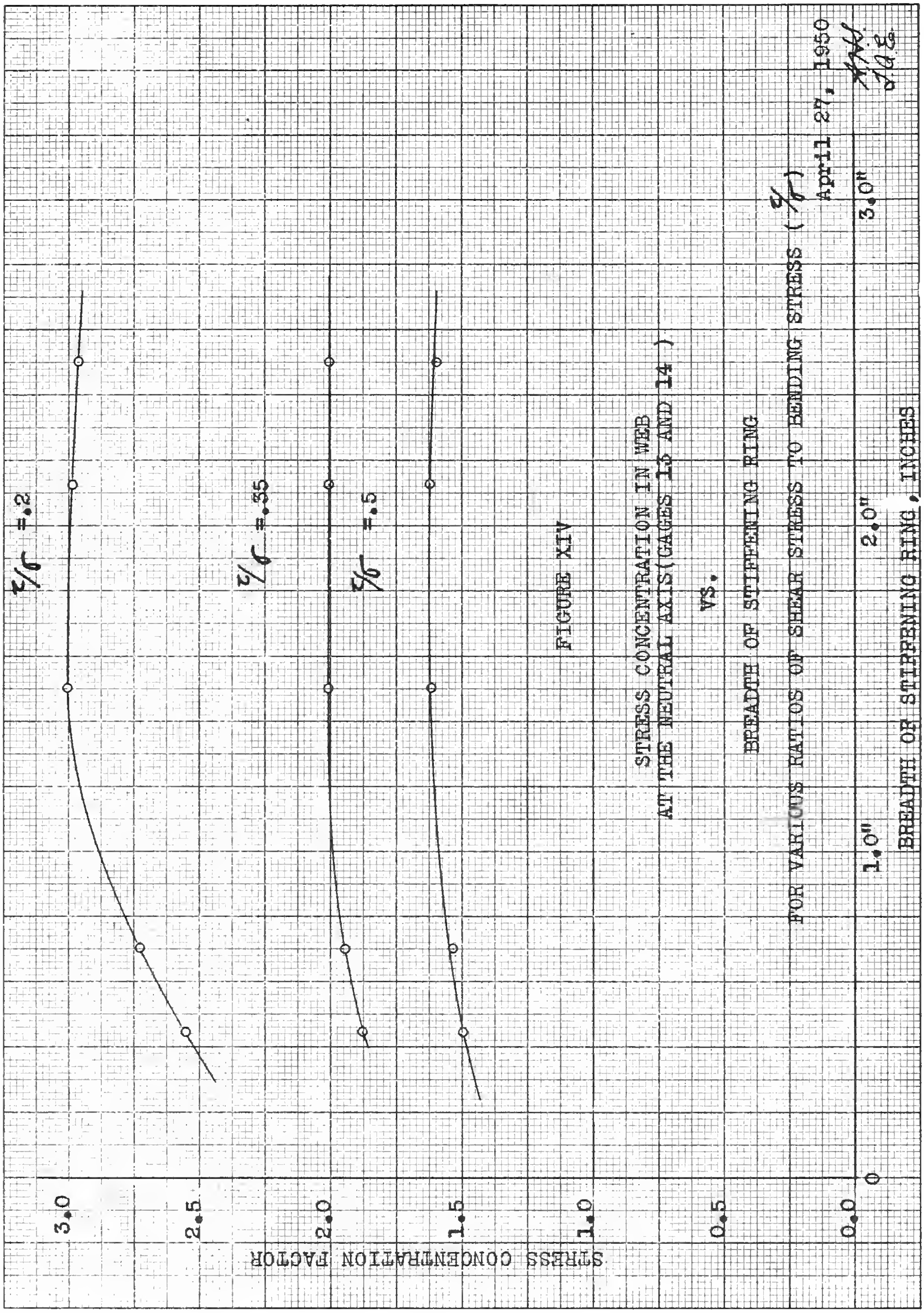


FIGURE XIV
STRESS CONCENTRATION IN WEB
AT THE NEUTRAL AXIS(GAGES 13 AND 14)
VS.
BREADTH OF STIFFENING RING
FOR VARIOUS RATIOS OF SHEAR STRESS TO BENDING STRESS (τ/σ)
April 27, 1950
τ/σ =.2
τ/σ =.35
τ/σ =.5
STRESS CONCENTRATION FACTOR
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1.0"
2.0"
3.0"
BREADTH OF STIFFENING RING, INCHES

Figure XIV-A

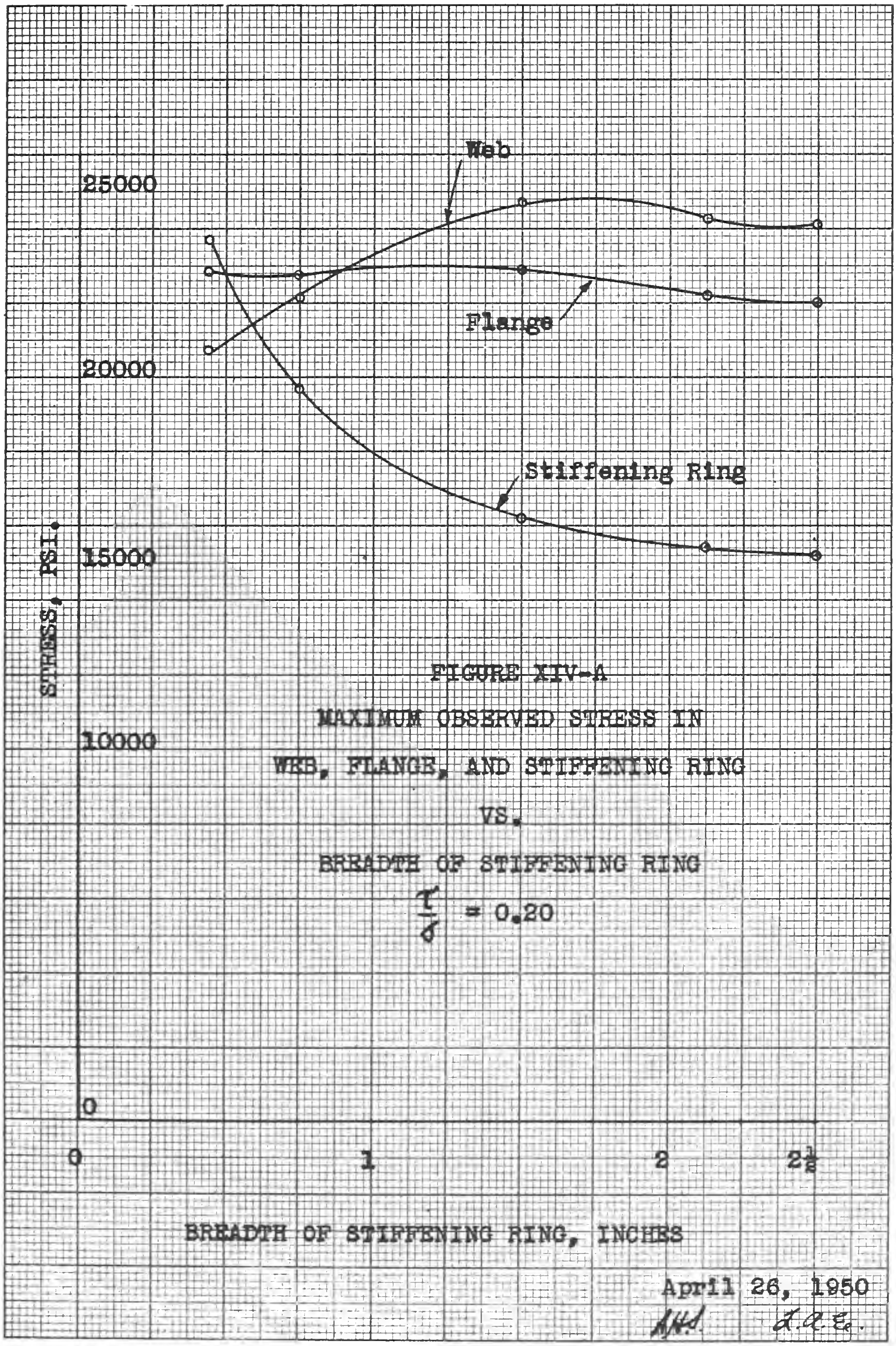

Web
Flange
Stiffening Ring
25000
20000
15000
10000
0
STRESS, PSI.
0
1
2
2½
FIGURE XIV-A
MAXIMUM OBSERVED STRESS IN
WEB, FLANGE, AND STIFFENING RING
VS.
BREADTH OF STIFFENING RING
$\frac{\tau}{\sigma}$ = 0.20
BREADTH OF STIFFENING RING, INCHES
April 26, 1950

Figure XIV-B

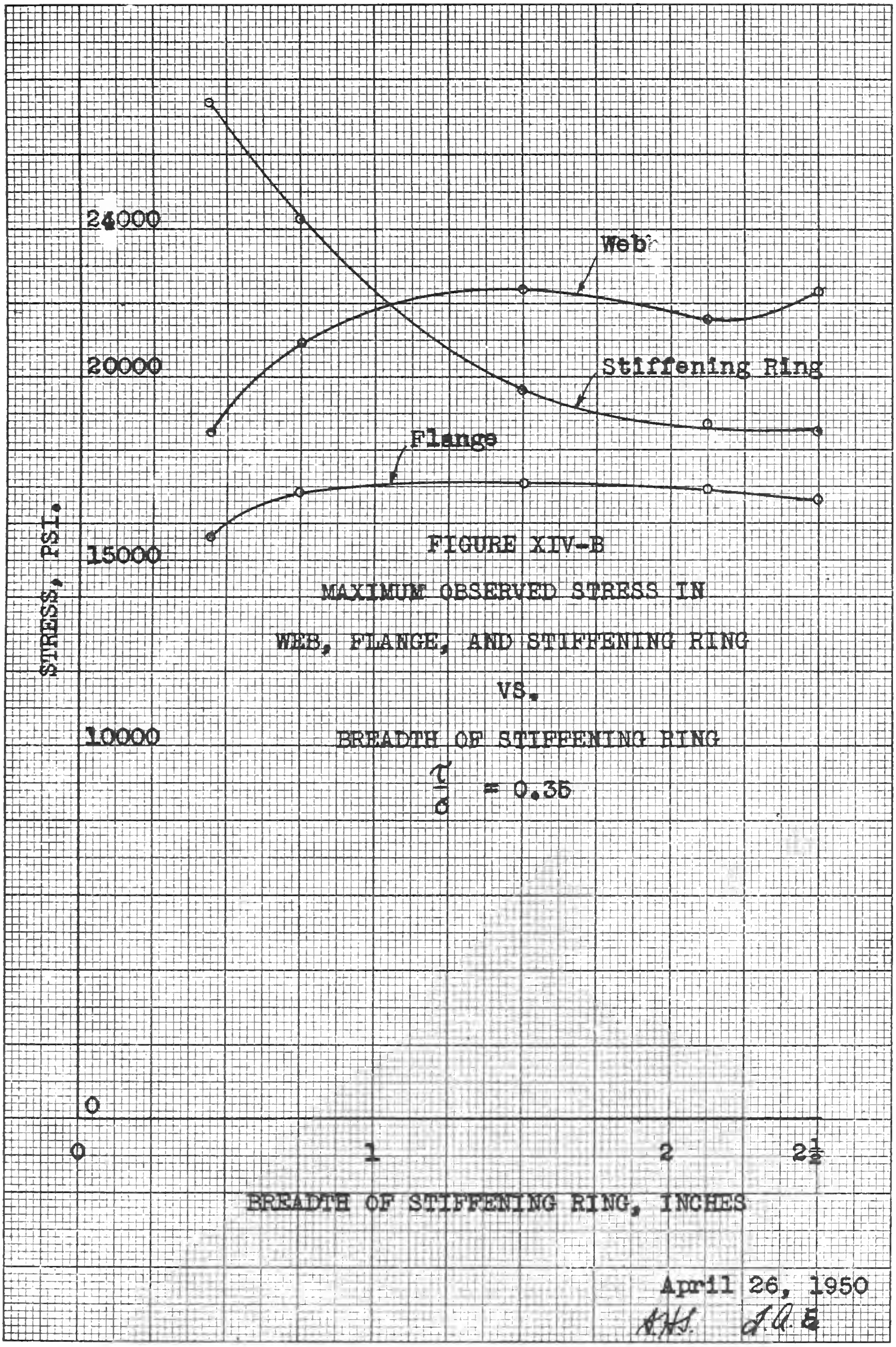

24000
20000
15000
10000
0
STRESS, PSI.
Web
Stiffening Ring
Flange
FIGURE XIV-B
MAXIMUM OBSERVED STRESS IN
WEB, FLANGE, AND STIFFENING RING
VS.
BREADTH OF STIFFENING RING
$\frac{\tau}{\sigma}$ = 0.35
0
1
2
$2\frac{1}{2}$
BREADTH OF STIFFENING RING, INCHES
April 26, 1950
A.H.S. J.Q.S.

Figure XIV-C

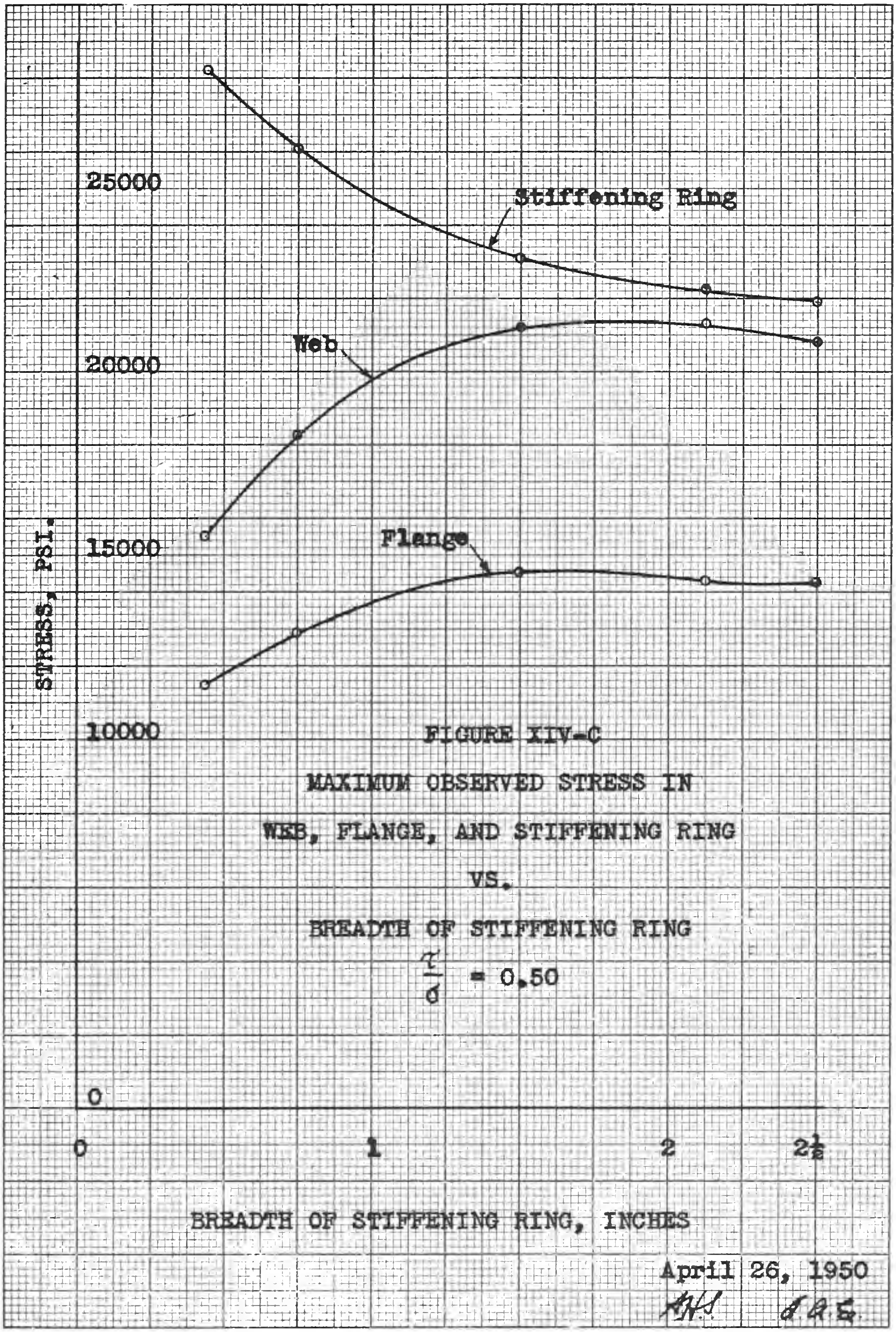
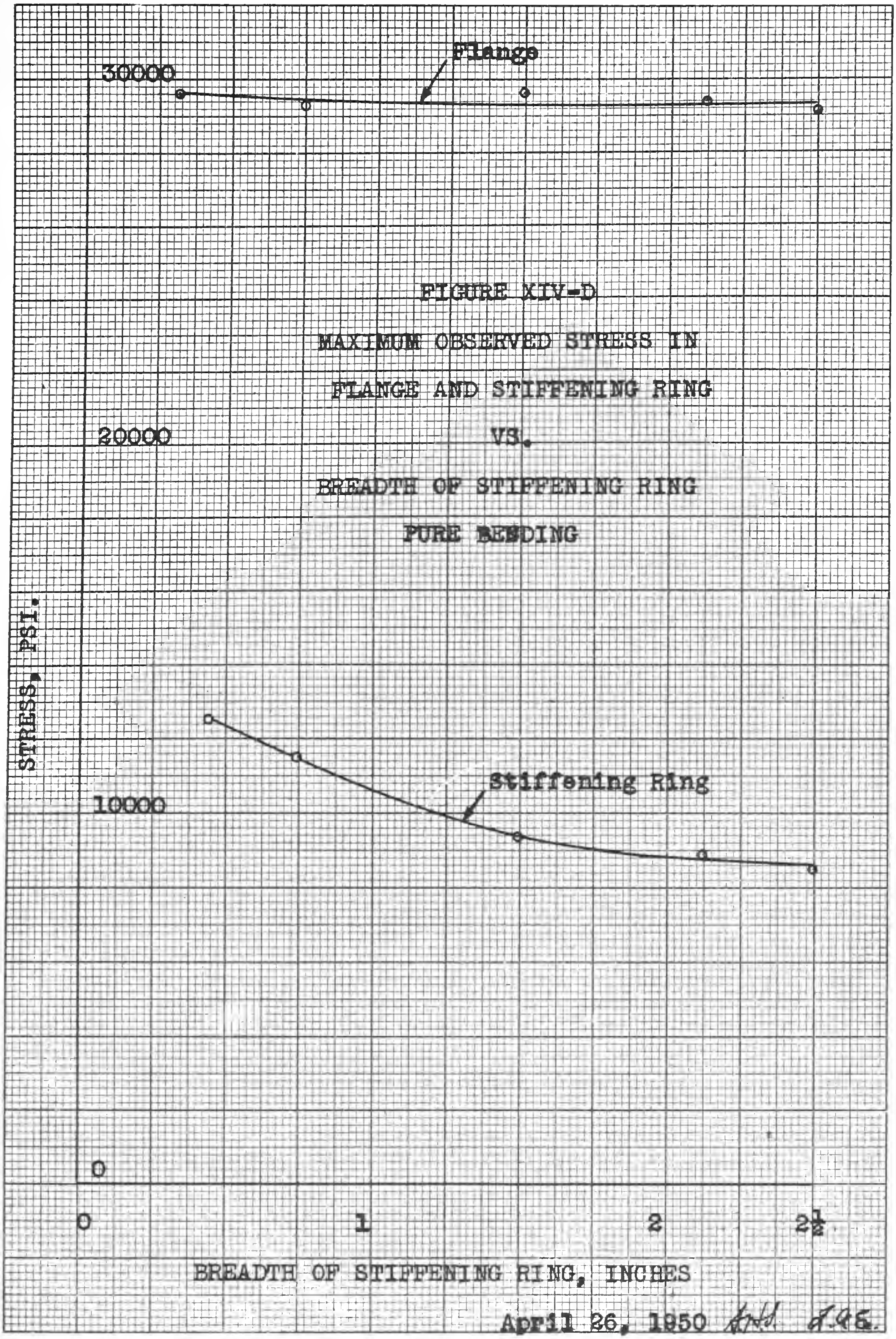

25000
20000
15000
10000
0
STRESS, PSI.
Stiffening Ring
Web
Flange
FIGURE XIV-C
MAXIMUM OBSERVED STRESS IN
WEB, FLANGE, AND STIFFENING RING
VS.
BREADTH OF STIFFENING RING
$\frac{\tau}{\sigma}$ = 0.50
0
1
2
$2\frac{1}{2}$
BREADTH OF STIFFENING RING, INCHES
April 26, 1950

Figure XIV-D


Flange
30000
20000
10000
0
STRESS, PSI.
FIGURE XIV-D
MAXIMUM OBSERVED STRESS IN
FLANGE AND STIFFENING RING
VS.
BREADTH OF STIFFENING RING
PURE BENDING
Stiffening Ring
0
1
2
2½
BREADTH OF STIFFENING RING, INCHES
April 26, 1950

V

DISCUSSION OF RESULTS

From a study of Tables I-V it is found that the location of the highest stress in the vicinity of the opening varies with τ/σ ratio and breadth of stiffening ring. Figures XIV-A,-B,-C, and-D show the magnitude of the maximum stress as derived from the gage readings for the most highly stressed points in the web, flanges and stiffening ring. The stresses for the web are taken from the readings of gages 13 and 14, those for the flanges from gages 20 and 21, and those for the stiffening ring from gage 17, except those for pure bending which are taken from gage 19, farthest from the neutral axis.

The web is the most highly stressed member at low τ/σ ratios, but at τ/σ = .50 or greater, the location of the greatest stress is in the stiffening ring. The magnitude of this ring stress is high, and it is evident that yielding will occur in the ring before the web and flange stresses reach even a moderate value. If the breadth of the ring is less than four times the thickness of the web, the ring is the most highly stressed member for τ/σ ratios above 0.35. When there is appreciable shear, it appears that there is always the likelihood of yielding in the ring, if its cross-sectional area is small. Hence for an unstiffened opening, the stresses will be high at the edge of the hole if there is appreciable shear.

Since the magnitude of the maximum web stress is always greater than the flange stress it is evident that yielding will take place in the web before it occurs at the extreme fibres, except when τ/σ is less than 0.20 and the breadth of the ring less than $3\frac{1}{2}$ times the web thickness (Figure XIV-A). Thus it is seen that the magnitude of the stress concentrations in the web and stiffening ring are greatly affected by the degree of shear.

Stiffening Ring

From the results obtained in pure bending, Figure VII, it is seen that the variation of stress concentration along the elliptical arc resembles closely the theoretical curve derived by Joseph and Brock (6) for an unreinforced ovaloid. Due to the fact that all reinforcement could not be removed without disturbing the gages installed, the stress concentration factors found for the elliptical hole are slightly less than the values given by the theoretical curve. Other differences between the observed and theoretical curves may be due to the difference in the shape of the opening. The experimental work of Karl, Heller, and Gerich (8), using a photoelastic model with an ovaloid opening, is also in good agreement with the theoretical curve. Both show that a reversal of stress takes place, as Figure VII indicates.

As shear is introduced, it is seen from Figures VIII, IX and X that the location of the maximum stress shifts toward the mid-length of the arc and is everywhere tensile. For $\tau/\sigma = 0.20$, the maximum value occurs

at about 55% of the arc length for each breadth, and shifts to about 60% for τ/σ = 0.35 and 0.50. It will be seen in Tables I-V that the concentration factors for the web gages, although smaller than those factors for the stiffening ring gages, show a slightly greater factor in each case for gages 7 and 8, situated nearly adjacent to the point for 60% of arc on the ring. Thus it is evident that the reinforcing ring is assuming a very large share of the load of the web in its vicinity.

Figures XI and XII are of most interest since they show the variation of maximum stress concentration factor with breadth of reinforcing ring and with loading condition respectively. With an increase of shear, the factor increases rather rapidly at first and then tends to approach a maximum value at a decreasing rate. At τ/σ = 0.5, the factor for the 7/16" ring is 1.6 times as great as that for the 2½" ring. The factor remains below 1.60 for breadths greater than 1½", but at lesser breadths there is a rapid increase. This ring breadth of 1½" may be compared with the breadth of 1.43", which would replace the weight removed from the beam in cutting the elliptical opening. Hence if stresses are to be kept within the yield point, it is evident that the weight of stiffening required will slightly exceed the weight removed in the opening.

The influence of shear may be seen clearly in Figure XII, where the curve for pure bending lies well below those for the conditions with shear. Taking as an example the values of the factor for the case of the 1½"

stiffening ring, in pure bending the factor is 0.92, whereas at $\tau/\sigma = 0.50$, the factor is 1.61, or an increase of 75%. Thus it appears again that the degree of shear to which the section is subjected is of considerable importance.

The results obtained in pure bending are in agreement with those obtained by Ryan and Fischer (4) for the case of an unreinforced circular opening. They found that when the ratio of the diameter of the opening to the depth of the beam is less than $\frac{1}{2}$, the maximum stress occurs in the outer edge of the beam. In the present case, the ratio of the minor axis of the elliptical opening to the depth of the beam is 0.362, and it will be found from Table V, minimum reinforcement, for the case of pure bending, that the maximum stresses occur in the outer edge or flange gages (nos. 20-29).

Web

The high stress concentration factors found at the location of gages 13 and 14 are of interest, since the calculated stress for the intact beam is least for this point on the neutral axis. It is seen from Figure XIII that the maximum factor obtained, 3.04, occurs at $\tau/\sigma = 0.20$ and is about the same for the $2\frac{1}{2}$", 2 1/8" and $1\frac{1}{2}$" stiffening ring. An increase of the factor with decrease of shear and increase of stiffening ring is contrary to the behavior of the factor for the case of the stresses in the stiffening ring itself, previously mentioned.

Neuber (7) showed in his theoretical solution for stresses around a small elliptical opening in a bar subjected to bending and shear that there was a marked stress concentration due to shear just beyond the ends of the opening on the major (neutral) axis, which decreased to zero at the edge of the bar. His analysis was based on an elongated elliptical opening in a bar of relatively great width compared to the width of the opening. Using his formula for the maximum shear stress concentration

$$\frac{\tau_{max.}}{2bd} = 3\,\frac{\left(\frac{t'}{\rho'} + 2\right)^{3/2} - \sqrt{\frac{t'}{\rho'}}}{\left(\sqrt{\frac{t'}{\rho'}} - 1\right)^{2}}$$

where t' = length of semi-major diameter

= radius of curvature of ellipse at end of semi-major diameter

b = ½ depth of the bar

d = thickness of the bar,

the maximum stress concentration factor is found to be 2.25 for the ellipse investigated. Since this calculated value is for an unreinforced opening and results show a decreasing value of stress concentration with reduction in stiffening ring width, the maximum stress concentration of 3.04 appears reasonable.

The stress concentration factor has been defined as the ratio of the observed stress to the theoretical stress of beam theory for the intact beam. The factor for gages 13 and 14 would therefore approach infinity in pure bending, since the theoretical stress is zero at the neutral axis. For the beam with the opening, the latter will of course not be the case, since stress will arise on the neutral axis because of the presence of the opening. This is the reason that the factor in Figures XIII and XIV approaches infinity as τ/σ approaches zero.

A consideration of the variables involved in the expression for the calculation of the principal stress from observed strains will indicate which of these variables is at this point exerting the greatest influence on the derived stress. Consider, for example, the values given in Table I for $\tau/\sigma = 0.20$ for gages 13 and 14. The strains $\epsilon_x = 315$, $\epsilon_y = -295$ are not significantly different in magnitude from the other web gages 1-12 and are nearly equal numerically but of opposite sign. The angle θ, however, has the value 36.2 degrees. Secant 2 θ, as used in the calculations, page , becomes secant 72.4 = 3.307, which is three times as large as its value for the angles in the case of the other web gages. Furthermore, a reasonable maximum error of 0.5 degree in measuring this angle from the stresscoat diagram, Figure XVI, would result in a change in secant 2 θ of 5.8%, which would be reflected in the value of the derived stress. Using equations (1), (2), and (3) given in the Appendix, page , in this case the stress concentration

factor would be changed by 4.4%, a figure which represents the maximum expected error for gages 13 and 14. It is evident, however, that this error is not sufficiently large to effect the validity of these results, which were confimed by the results of the later tests with the supplementary "A" gages located at the former position of gages 13 and 14, as shown in Figure XXIV. The results obtained from gages 7A, 8A, and 9A in the Appendix, page 66, indicate that a stress concentration of the same order of magnitude occurs on the other side of the ellipse. At gages other than 13 and 14, the factors obtained for stresses in the web are comparatively low.

<u>Flanges</u>

The stress concentration factor on the outer surface of the flanges of the beam is invariable below unity, except for pure bending, where it reaches its maximum observed value of 1.03 for the $\frac{7}{16}$" ring in Table V. The factor decreases moderately with increase of $\frac{\tau}{\sigma}$ ratio for constant ring breadth but does not show any appreciable change with variation of ring breadth at constant $\frac{\tau}{\sigma}$. This indicates that the maximum stress in the flanges is very little affected by a web discontinuity of the proportions tested, a result substantiated by previous investigators (4).

For conditions of loading other than pure bending, the factor shows its greatest value on the flange in way of the centerline of the opening (gages 20, 21). It decreases moderately with distance toward the left

support, but rises to another maximum (less than the first) in way of the left end of the ellipse (gages 28, 29), never attaining, however, values greater than unity.

For the case of pure bending, the situation is reversed. Here the minimum factor always occurs at the centerline of the hole, while all gages to the left show slightly higher values, never exceeding 1.03. A typical variation of the factor with distance from the vertical centerline of the ellipse is shown in Figure XLIII.

Figures XXII to XXXIX inclusive show the relationship between load and gage reading for every gage for the tests of the $1\frac{1}{2}$" stiffening ring breadth. It is seen that this relationship is essentially linear after initial loading has removed any transverse twist in the beam due to errors of manufacture. After the stiffened opening was fabricated into the beam, it was discovered that the centerline of the web was offset 1/8" from the centerline of the flanges. It is felt, however, that this fact does not appreciably affect the accuracy of the results.

VI

CONCLUSIONS

1. Stress concentrations do exist around a reinforced elliptical discontinuity in a beam subjected to complex bending.
2. If the thickness of the reinforcing ring is the same as that of the web, it appears that, from the relative magnitude of the stresses, yielding will take place in the web at the neutral axis before it occurs in the extreme fibres, if τ/σ is greater than 0.20 and the breadth of the ring is less than $3\frac{1}{2}$ times the thickness.
3. Yielding will occur first in the stiffening ring if τ/σ is greater than 0.50, irrespective of the breadth of the ring. If the breadth is reduced to 4 times the thickness, yielding will occur first in the ring if τ/σ is greater than 0.35.
4. The magnitude of the stress concentration in the reinforcement varies directly with the degree of shear and inversely with its cross-sectional area. The variation is not linear.
5. The magnitude of the principal stress concentration in the web of the beam at the neutral axis varies inversely with the degree of shear and directly with the cross-sectional area of the reinforcement. The variation is not linear.

6. The magnitude of the stress at the most extreme fibres of a wide flange I beam is very little affected by the presence of a centrally-located elliptical discontinuity, reinforced or unreinforced, whose depth is less than 0.36 times the depth of the beam.

7. In pure bending, the stress concentration factor nowhere greatly exceeds unity. In the stiffening ring, a reversal of stress occurs which disappears with the introduction of shear.

8. Stress concentration factors for the beam are not materially influenced by the width of reinforcing ring until the width is reduced below 7 times the thickness of the web.

VII

RECOMMENDATIONS

The authors recommend that

1. Further investigation be made of the stress distribution along the neutral axis of a beam in the vicinity of a reinforced discontinuity, the beam being loaded in complex bending.
2. A series of tests of ultimate strength be conducted for beams with various breadths of reinforcing ring. Since some local yielding due to high tensile concentrations is not harmful, the ultimate strength of the beam with the stiffened opening may actually exceed that of the intact beam.
3. For an opening constructed and reinforced similarly to the one tested, that the breadth of the reinforcing ring be not less than 7 times the thickness of the web.

VIII

APPENDIX

APPENDIX A

DETAILS OF PROCEDURE

A. Beam Selection and Fabrication

The decision having been made to test a beam with a reinforced elliptical discontinuity in complex bending, it was first necessary to decide on parameters and their variation. The parameters chosen were the variation in width of the flat bar stiffening ring and the variation of the ratio of nominal shear stress to bending stress in the intact beam at a section corresponding to the center of the major axis of the elliptical opening. The beam was simply supported, the load being applied at a point 21.5 inches from the center of the hole, and the variation in the ratio of shear stress to bending was effected by varying the distance of the support beyond the hole, as shown in the loading diagrams, Figure II.

The value of shear used in determining the ratio of nominal shear stress to bending stress, hereinafter referred to as τ/σ was obtained by dividing the magnitude of the variable reaction "v" by the product of the depth of the beam "h" times the thickness of the web t, i. e.,

$$\tau = \frac{v}{h\,t} .$$

The bending stress used was that obtained at the surface of the beam flanges as calculated by the ordinary bending stress formula,

$$\sigma = \frac{m\,y}{I} .$$

It was desirable to have as large a variation in the ratio of shear stress to bending stress as possible and, with this in mind, a 12" x $6\frac{1}{2}$" x 25# wide flange beam, eleven feet long was selected. This choice was also influenced by the size of the testing machine available as pertains to length and flange width of the specimen, and the desire to have a beam which could be handled easily. A depth of less than twelve inches did not appear feasible considering the amount of space required for strain gage installation.

The elliptically shaped hole was chosen since it permits a large access area for a given beam depth. The true elliptical shape was used in preference to two semi-circles joined by a straight section, since Obermeyer and Ballinger (5) found stress concentrations were set up at the points of tangency of the straight and semi-circular sections. The hole cut in the beam before the reinforcement was installed was 4.8 inches high by 7.2 inches long. This corresponds to a height of 0.4 of the beam depth and the major axis of the ellipse 1.5 times minor axis.

A high tensile steel beam was obtained from and the stiffening ring installed at the Boston Naval Shipyard. The stiffening ring was fabricated from a $\frac{1}{4}$" x $2\frac{1}{2}$" mild steel flat bar and welded into the elliptical hole in two sections, with a v- weld at each end of the ellipse at the neutral axis as shown in Figure I. In addition to the installation of the stiffening ring, additional web stiffeners, cut from 10 pound plate,

were installed on either side of the web at a distance of 31 and 62 inches to the right of the hole center line as shown in Figure 2. These stiffeners were installed to reduce any tendency of the beam to twist and to carry the concentrated load into the beam web.

After all welding had been completed, the entire beam was placed in a furnace and stress relieved. The temperature in the furnace was raised from room temperature to approximately 1125°F at a steady rate over a period of 6 hours and 45 minutes. The furnace temperature was maintained at 1125°F for 1 hour, then the furnace was secured and the beam allowed to cool in the furnace for approximately 17 hours.

A standard flat plate tensile specimen in accordance with ASTM specifications was cut from the web of an excess portion of the beam to determine the modulus of elasticity. The modulus of elasticity was obtained as shown in Figure XL and Table XIII. A corresponding tensile specimen was made from a $\frac{1}{4}$" x $2\frac{1}{2}$" mild steel flat bar to determine the modulus of elasticity of the stiffening ring. The results of this tensile test are shown in Figure XLI and Table XIV. Both tensile tests were performed in the Baldwin Southwark 60,000 pound testing machine and the strains were measured by a pair of Huggenberger Tensometer gages mounted opposite each other to eliminate any bending effects.

B. Stress Coat Tests

In order to determine the lines of principal tensile strain around the access hole, it was necessary to run a series of stress coat tests. Stresscoat is sensitive to temperature and humidity which determine the

proper coating for any given atmospheric conditions. Psychrometer readings of wet-and-dry-bulb air temperatures were taken in the room where the specimen was coated and allowed to dry. Using these two temperature readings, the stresscoat calibration chart was entered and the specified coat selected. The area to be stresscoated was carefully power wire brushed and cleaned with a solvent (Methylisobutylketone). An aluminum-pigmented undercoating was sprayed over the surface in order to accentuate the stress coat cracks. After the aluminum coat had dried about 15 minutes, the stresscoat was sprayed on, using care to spray the coat on evenly and not too thick. Calibration strips were coated with stresscoat at the same time as the beam. The calibration strips, when loaded as a cantilever in the calibrating device, show the approximate sensitivity of the coat which has been applied to the specimen being tested. The nearer the strain cracks approach the point where the calibration strip is loaded, the more sensitive the coating, i. e., the less stress is required to crack it. After allowing the coating to dry 24 hours, the beam was tested for $\tau/\sigma = 0.2$, but the results were inconclusive. The stresscoat was crazed and the 55,000 pound load on the beam was insufficient to crack the stress coat excepting a small area in the web near the outer flanges. The calibration strips showed a strain sensitivity of 0.0006 corresponding to a stress of approximately 18,000 pounds per square inch.

This stress coat was removed, the beam cleaned, and another coat applied, using the procedure described above. The technique for spraying the stress coat was better and a more uniform coat was obtained. The strain sensitivity for this coat was 0.00112, corresponding to about 33,000 psi required to crack the stress coat. This figure, coupled with the previous test, showed that the coat must be made more sensitive if any cracks were to be obtained. Due to the method of loading and the stress concentration directly beneath the load, the beam would yield at this section before it was possible to have sufficiently high stresses in way of the hole to crack the stresscoat possessing this low sensitivity. The beam was loaded to approximately 40,000 pounds and the area to which the stresscoat had been applied was suddenly cooled by a blast from a CO_2 fire extinguisher. A pattern of very fine cracks was obtained. These cracks were viewed most clearly by shining a flashlight on the surface at an angle in order to accentuate the discontinuities in the stress coat surface. To obtain a permanent record of these crack patterns, the contour of the cracks was first sketched on the beam in soft red pencil and then copied directly on tracing paper which was cut to fit on the beam web over the stress coated area. This tracing was oriented by centerlines scribed on the beam. An alternative method of recording the cracks is to use a red dye etch on the surface, wipe it off and photograph the strain pattern as outlined by the dye remaining in the cracks. However, the strain lines are so close together when obtained by suddenly chilling the beam that differentiation between the lines is rather poor.

The tracing procedure proved satisfactory and was used to record the strain cracks for τ/σ = 0.2, 0.5 and pure bending as shown in Figures XV thru XVII.

C. Strain Gage Installation

The stress coat tests gave lines which were normal to the principal tensile strains. Because of the expense of the gages and limitation of time, only one quadrant of the ellipse was selected for detailed investigation. Figures XV and XVI showed that the greatest positive strains in the stiffening ring would occur in the lower left hand quadrant for the beam oriented as shown with the load to the right side of the hole; accordingly this quadrant was investigated.

The desire to get as near the stiffening ring as possible on the web, and to have the strains at a number of points, necessitated a relatively small strain gage, and precluded use of the rosette type. The gage best suiting these conditions as determined from Baldwin Bulletins (9-10) was the type A-8, SR-4 cupro nickel wire strain gage. These gages have a 1/8 inch gage length so the strains measured were quite well pin-pointed. To limit the number of gages to be installed in the web, only seven gages were applied to each side with the adjacent gages oriented normal to each other as shown in Figure I. In order to utilize this method, it was essential that none of the strain gages make an angle of 45° with any of the lines of principal strains, because in combining the measured strains in Mohr's circle using twice the angle between the axis of the gage and a line normal to the strain cracks at

the gage, an indeterminate condition would obtain if this angle were 45°. With this in mind, it was found by examining the stress coat patterns for all conditions of loading that the optimum gage orientation was 20° to the horizontal axis of the beam, with alternate gages normal to this orientation. Gages were placed in the same position and orientation on opposite sides of the web to eliminate the effect of any bending or twisting which might be introduced.

Five gages were placed inside the stiffening ring extending from the major axis to the minor axis of the elliptical arc chosen for investigation. These gages were placed in the vertical centerline plane of the web. Ten gages were placed on the top and bottom flanges of the beam, in a line coinciding with the centerline of the web and extending from the vertical centerline of the ellipse to a point approximately the same distance out as the gages installed on the neutral axis. It was desired to measure the strains in the flanges as well as the strains about the hole since Ryan and Fischer (4) found in studying beams with a central hole subjected to pure bending, that, if the ratio of the diameter of the hole to the depth of beam is less than $\frac{1}{2}$, the maximum stress occurs on the outer edge of the beam and is approximately equal to the stress in the beam without the hole. If the ratio is greater than $\frac{1}{2}$ the edge of the hole becomes critical.

With the gage locations established, the area to receive gages was roughened with No. 000 sand paper and each gage location marked on the beam. Duco Household Cement was used to cement the strain gages in place.

The gages were covered with sponge rubber backed by a piece of 3-ply wood and held in place by clamps. The clamps were tightened just sufficiently to hold the sponge rubber in place. The clamps were removed after two days, but the gages were allowed to dry for a week before being used. Before soldering on leads of No. 20 copper wire, all the gages were checked by means of a volt-ohmmeter for continuity, grounds and specified resistance. All connections were soldered using rosin core solder.

D. Instrumentation

The instruments used to measure the strains were two Baldwin SR-4 Twenty-point switching units and a Baldwin Portable Strain Indicator, Model K. The switching unit combines a unique circuit which virtually eliminates all errors due to contact resistance. One dummy gage was used for all measurements and was mounted on the tensile test specimen taken from the beam web. During all tests this specimen was resting on the lower flange of the beam adjacent to the gages being tested, as can be seen in Figure VI. In order to utilize only one dummy gage with the switching units, all the dummy gage terminals on the end of the switching units were connected in series by a bare copper wire. The dummy gage terminals in the two switching units were then connected together. This wiring set up, as shown schematically in Figure XLII, permitted all gages to be switched into the Strain Indicator without shifting any connections.

E. Recording of Data

With the beam installed in the 100,000 pound Riehle testing machine as shown by the loading diagrams, Figure II and photographs Figures III through VI and all the instruments and gages properly connected, it was possible to start recording data. With the beam in position for a given ratio of shear stress to bending stress, or pure bending, as the case might be, an initial reading was taken for all strain gages using the strain indicator, which gives readings directly in micro-inches. The load was applied in four increments up to the maximum load and then decreased by the same increments down to zero. Strain readings were recorded for each increment of load, both increasing and decreasing. The strain for each load in each case is the difference between the value read at the load and the initial reading. Approximately 1½ hours were required to make a complete set of readings for a given τ/σ ratio. Readings were taken both for increasing load and decreasing load in order to check the reliability of the gages. Figures XXVII through XXXIX show load vs. strain for all gages when the stiffening ring was 1½ inches wide.

F. Method of Reducing Width of Stiffening Ring

The stiffening ring width was reduced by clamping the beam, with the web horizontal, in a shaper then cutting transversely across the ring from one side to the other. This method proved very effective since the rate of cutting was slow enough that the heat generated was

insufficient to adversely affect the installed strain gages. However, it required extensive handling of the beam, since the shaper was located in the basement below the testing machine. In an attempt to eliminate unnecessary handling, the first reduction in stiffening ring width from $2\frac{1}{2}$ to 2 1/8 inches was accomplished by using a $\frac{1}{4}$" x 9 inch diameter cutting-off wheel driven by an air motor. The air motor was mounted in a jig which rested on the edges of the beam flanges so that the plane of the cutting off wheel was parallel to the beam web. This method proved unsatisfactory because the heat generated necessitated light cuts with intervals for cooling and required an excessive amount of time to perform the operation. As the width of the stiffening ring approached the thickness of the web there was danger of a chip damaging the gages installed on the web. The trim width of the A-8 gages installed on the stiffening ring was 5/16 of an inch while the web thickness was 0.24 inches. For these reasons the stiffening ring width was not reduced below 7/16 inch which allowed approximately 0.1 inch on each side of the web.

G. Stresscoat Test After Stiffening Ring Reduced to 7/16"

After completion of all strain gage measurements it was deemed desirable to make another stresscoat test to determine whether there was any appreciable change in the direction of the strain cracks after the stiffening ring had been reduced to 7/16 inch. This necessitated the removal of all the strain gages applied to the web. With the beam

stress coated as before it was tested for a value of τ/σ = 0.5. The results of this test are shown in Figure XVIII, and also are shown superimposed for comparison on the original pattern for this ratio of τ/σ in Figure XV.

H. Installation of Supplementary "A" Gages on the Neutral Axis

As a result of calculation based on the original data, it appeared that an extraordinary high stress concentration existed at the point where gages 13 and 14 were installed on the neutral axis. Since the strains normal to the orientation of gages 13 and 14 were extrapolated from gages 11 and 12 in the manner shown in Figures XIX through XXIII, it seemed advisable to obtain these normal strains as near to gages 13 and 14 as possible by direct measurement. Therefore, gages were reinstalled at the same location with the same orientation as gages 13 and 14, plus two more pairs of gages as close as possible on either side of the neutral axis and oriented normal to the orientation of gages 13 and 14 as shown in Figure XXIV. Use of rosette type gages was precluded by space considerations. Gages were also placed in a similar location at the opposite end of the elliptical opening, but only on one side of the beam, because no additional gages were available. The weld in the stiffening ring adjacent to gages 13 and 14 had a flaw which became apparent when the stiffening ring was reduced down to 3/4 inch width. It was thought that this flaw may have given rise to the stress concentration noted at gages 13 and 14 which are approximately 3/4 inch from the flaw. Since the weld was apparently satisfactory on the opposite side of the ellipse, the

installations of gages here would indicate whether the weld had a marked influence on the stress concentration factor. The location of these gages is shown in Figure XXIV. Following their installation, and, using the same procedure as before, the beam was tested again for $\frac{c}{\sigma}$ = 0.2, 0.35, 0.5 and pure bending, and the data recorded as previously.

In order to obtain strains normal to the strains for gages 13 and 14 for all widths of stiffening ring an interpolation plot, Figure XXIV-A, was made from data obtained using the supplementary gages. Provided the material is not stressed beyond the yield point, the ratio of strains which are mutually perpendicular at a given point are constant for each loading condition. Therefore, the average strains for gages 1A, 2A, 5A and 6A were plotted vs. the average strains for gages 3A and 4A for each increment of load. Then, for any stiffening ring width, to obtain the strains normal to gages 13 and 14 which were located and oriented the same as the supplementary gages 3A and 4A, it is only necessary to enter Figure XXIV-A with the value of strain read by gages 13 and 14 and read off the corresponding normal strain. The method actually used in Table XII consisted of multiplying the strains measured by gages 13 and 14 by the tangent of the angle α shown in Figure XXIV-A.

APPENDIX B

SUMMARY OF DATA AND CALCULATIONS

TABLE I

Observed Strains and Stress Concentration Factor for Each Gage Location
Stiffening Ring Breadth = $2\frac{1}{2}$"

Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1 (calc) psi	Stress conc. factor
τ/σ = 0.20, Load 37740 Lbs.								
1,2	480	-208	10.8	505.9	-233.9	14490	15540	.93
3,4	435	-100	80.3	451.1	-116.1	13810	15190	.91
5,6	408	- 5	5.4	411.7	- 8.7	13540	14710	.92
7,8	405	15	88.5	405.2	14.8	13550	13840	.98
9,10	405	- 58	0.0	405.0	- 58.0	12840	12600	1.02
11,12	385	-255	83.6	393.2	-263.2	10480	10450	1.00
13,14	315	-295	36.2	1016.6	-998.6	24120	8123	2.96
15				62.0		1753	8215	.21
16				418.0		11820	9812	1.20
17				538.0		15210	11310	1.34
18				445.0		12580	12590	1.00
19				230.0		6504	13060	.50
20,21				728.0		22060	23090	.96
22,23				702.0		21270	22590	.94
24,25				676.0		20480	22130	.93
26,27				654.0		19820	21820	.90
28,29				660.0		20000	21340	.94
τ/σ = 0.35, Load 40000 Lbs.								
1,2	464	-298	12.1	501.0	-335.0	13360	15600	.86
3,4	406	-136	77.7	433.0	-163.0	12760	15250	.84
5,6	387	0	14.2	413.5	- 26.5	13420	14890	.90
7,8	390	28	74.7	419.3	- 1.3	13858	14330	.97
9,10	400	- 50	1.5	400.3	- 50.3	12760	13560	.94
11,12	418	-308	84.2	425.7	-315.7	11050	12190	.91
13,14	420	-409	31.9	944.3	-933.3	22284	10700	2.08
15				85.0		2404	10800	.22
16				564.0		15950	11880	1.34
17				654.0		18490	12860	1.44
18				449.0		12700	13710	.93
19				156.0		4411	14040	.31
20,21				549.0		16630	17490	.95
22,23				486.0		14720	16840	.88
24,25				451.0		13660	16220	.84
26,27				429.0		13000	15800	.82
28,29				436.0		13210	15170	.87

TABLE I (cont'd)

Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1 (calc.) psi	Stress conc. factor
τ/σ = 0.50, Load 44000 Lbs.								
1,2	490	-375	13.5	543.4	-427.9	13870	16870	.82
3,4	420	-161	75.1	464.3	-205.3	13390	16570	.81
5,6	399	15	23.0	483.4	- 69.4	15320	16230	.94
7,8	408	52	60.9	567.8	-107.8	17750	15820	1.12
9,10	430	- 38	3.0	431.3	- 39.3	13890	15230	.91
11,12	479	-359	84.7	486.3	-366.3	12570	14170	.89
13,14	505	-486	27.6	877.7	-858.7	20790	13070	1.59
15				119.0		3365	13160	.25
16				686.0		19400	13980	1.39
17				774.0		21890	14740	1.49
18				486.0		13740	15410	.89
19				128.0		3620	15710	.23
20,21				470.0		14240	14960	.95
22,23				380.0		11510	14160	.81
24,25				342.0		10360	13410	.77
26,27				322.0		9756	12890	.76
28,29				317.0		9605	12120	.79
Pure Bending, Load 44000 Lbs.								
1,2	364	13	21.4	427.7	- 50.7	13660	14610	.94
3,4	342	2	59.0	534.1	-190.1	15850	14080	1.12
5,6	330	- 11	28.1	466.0	-147.0	14000	13450	1.04
7,8	322	- 22.5	62.6	448.5	-149.0	13410	12120	1.11
9,10	297	- 33	24.4	382.5	-118.5	11516	9980	1.15
11,12	185	- 47	78.0	196.0	- 58.0	5928	5780	1.03
13,14	5	- 52						
15				4.0		113	387	.29
16				8.0		226	4365	.05
17				118.0		3337	7475	.45
18				296.0		8371	9712	.86
19				301.0		8512	10420	.82
20,21				928.0		28120	28870	.97
22,23				926.0		28060	28870	.97
24,25								
26,27				958.0		29030	28870	1.01
28,29				961.0		29120	28870	1.01

TABLE II

Observed Strains and Stress Concentration Factor for Each Gage Location
Stiffening Ring Breadth = 2-1/8"

Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1 (calc) psi	Stress conc. factor
r/c = 0.20, Load 37740 Lbs.								
1,2	492	-230	10.8	519.3	-257.3	14710	15540	.95
3,4	445	- 89	80.3	461.1	-105.1	14240	15190	.94
5,6	420	0	5.4	423.8	- 3.8	13980	14710	.95
7,8	420	19	88.5	420.3	18.7	14080	13840	1.02
9,10	420	- 55	0.0	420.0	- 55.0	13360	12590	1.06
11,12	375	-245	83.6	382.9	-252.9	10240	10450	.98
13,14	317	-295	36.2	1022.9	-1000.9	24230	8123	2.98
15				60.0		1697	8215	.21
16				427.0		12070	9812	1.23
17				545.0		15410	11310	1.36
18				465.0		13150	12580	1.05
19				248.0		7013	13060	.54
20,21				734.0		22240	23090	.96
22,23				701.0		21240	22590	.94
24,25				663.0		20090	22140	.95
26,27				659.0		19970	21820	.91
28,29				663.0		20090	21342	.94
r/c = 0.35, Load 40000 Lbs.								
1,2	475	-325	12.1	513.9	-363.9	13510	15600	.87
3,4	415	-127	77.7	432.0	-154.0	12810	15250	.84
5,6	398	3	14.2	425.0	- 24.0	13830	14890	.93
7,8	403	33	74.7	432.9	3.1	14350	14330	1.00
9,10	412	- 59	1.5	412.3	- 59.3	13070	13570	.96
11,12	409	-358	84.2	468.2	-417.2	11480	12190	.94
13,14	405	-389	31.9	967.2	-891.2	21460	10700	2.01
15				85.0		2404	10800	.22
16				568.0		16060	11880	1.35
17				661.0		18690	12860	1.45
18				460.0		13010	13710	.95
19				163.0		4610	14040	.33
20,21				557.0		16880	17490	.96
22,23				495.0		15000	16840	.89
24,25				459.0		13910	16220	.86
26,27				442.0		13390	15800	.85
28,29				443.0		13420	15170	.88

TABLE II (cont'd)

r/c = .50, Load 44000 Lbs.								
Gage No.	ϵ_x $\times 10^6$	ϵ_y $\times 10^6$	θ degrees	ϵ_1 $\times 10^6$	ϵ_2 $\times 10^6$	σ_1 psi	σ_1 (calc) psi	Stress conc. factor
1,2	498	-450	13.5	556.0	-508.0	13520	16870	.80
3,4	426	-165	75.1	471.0	-210.0	13570	16570	.82
5,6	408	7	23.0	496.1	- 81.1	15630	16230	.96
7,8	415	45	60.9	581.1	-121.1	18060	15820	1.14
9,10	433	- 36	3.0	434.3	- 37.3	14010	15230	.92
11,12	482	-405	84.7	479.5	-402.5	10330	14170	.73
13,14	518	-498	27.6	900.1	-880.1	21330	13070	1.63
15				101.0		2856	13160	.22
16				705.0		19940	13980	1.43
17				786.0		22230	14740	1.51
18				501.0		14170	15410	.92
19				138.0		3903	15720	.25
20,21				473.0		14330	14765	.96
22,23				393.0		11190	14170	.81
24,25				347.0		10510	13420	.78
26,27				325.0		9847	12900	.76
28,29				326.0		9878	12130	.81
Pure Bending, Load 44000 Lbs.								
1,2	384	18	21.4	450.4	- 48.4	14440	14610	.99
3,4	368	2	59.0	574.8	-204.8	17050	14080	1.21
5,6	345	- 15	28.1	488.6	-158.6	14640	13450	1.09
7,8	329	- 24	62.6	458.7	-153.7	13700	12120	1.13
9,10	313	- 30	24.4	401.9	-118.9	12150	9980	1.22
11,12	193	- 35	78.0	203.8	- 45.8	6302	5780	1.09
13,14	11	- 33						
15				5.0		141	387	.36
16				1.0		28	4365	.06
17				132.0		3733	7475	.50
18				307.0		8682	9712	.89
19				317.0		8965	10420	.86
20,21				940.0		28480	28870	.99
22,23				954.0		28900	28870	1.00
24,25				972.0		29450	28870	1.02
26,27				965.0		29240	28870	1.01
28,29				972.0		29450	28870	1.02

TABLE III

Observed Strains and Stress Concentration Factor for Each Gage Location
Stiffening Ring Breadth = $1\frac{1}{2}$"

Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1 (calc) psi	Stress conc. factor
				t/δ = 0.20, Load 37987 Lbs.				
1,2	506	-186	10.8	532.1	-212.1	15570	15540	1.00
3,4	475	-100	80.3	491.3	-117.3	15130	15190	1.00
5,6	447	- 23	5.4	451.2	- 27.2	14665	14710	.99
7,8	440	12	88.5	440.3	11.7	14450	13840	1.04
9,10	434	- 48	0.0	434.0	- 48.0	13900	12590	1.10
11,12	374	-241	83.6	380.8	-248.8	10210	10450	.98
13,14	323	-301	36.2	1042.7	-1020.7	24700	8123	3.04
15				53.0		1500	8276	.18
16				445.0		12580	9880	1.27
17				571.0		16150	11390	1.42
18				506.0		14310	12670	1.13
19				264.0		7460	13150	.57
20,21				755.0		22880	23250	.98
22,23				715.0		21660	22750	.95
24,25				694.0		21030	22290	.92
26,27				674.0		20420	21970	.93
28,29				678.0		20540	21490	.95
				t/δ = 0.35, Load 39945 Lbs.				
1,2	481	-270	12.1	516.4	-306.4	14140	15600	.91
3,4	423	-137	77.7	450.9	-164.9	13330	15250	.87
5,6	419	- 23	14.2	449.2	- 30.2	14570	14890	.98
7,8	421	27	74.7	452.9	- 4.9	14940	14330	1.04
9,10	422	- 38	1.5	422.3	- 38.3	13600	13570	1.00
11,12	423	-302	84.2	431.7	-309.7	11310	12190	.93
13,14	423	-407	31.9	948.0	932.0	22420	10700	2.09
15				73.0		2064	10800	.19
16				590.0		16680	11880	1.40
17				694.0		19630	12860	1.53
18				508.0		14370	13710	1.05
19				185.0		5230	14040	.37
20,21				564.0		17090	17500	.98
22,23				502.0		15210	16841	.90
24,25				463.0		14030	16225	.86
26,27				444.0		13450	15800	.85
28,29				448.0		13570	15170	.89

TABLE III (cont'd)

τ/σ = 0.50, Load 43950 Lbs.								
Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1 (calc) psi	Stress conc. factor
1,2	496	-355	13.5	547.0	-407.0	14190	16870	.84
3,4	462	-170	75.1	510.1	-218.1	14780	16570	.89
5,6	429	- 18	23.0	544.0	-116.0	16880	16230	1.04
7,8	427	41	60.9	600.2	-132.2	18580	15820	1.17
9,10	443	- 38	3.0	444.3	- 39.3	14320	15230	.94
11,12	490	-357	84.7	496.4	-364.4	12920	14170	.91
13,14	515	-495	27.6	894.9	-874.9	21210	13070	1.62
15				98.0		2770	13160	.21
16				727.0		20560	13980	1.47
17				816.0		23080	14740	1.57
18				540.0		15270	15410	.99
19				140.0		3960	15720	.25
20,21				478.0		14480	14965	.97
22,23				398.0		12060	14170	.85
24,25				346.0		10480	13420	.78
26,27				328.0		9938	12900	.77
28,29				327.0		9908	12130	.82
Pure Bending, Load 43980 Lbs.								
1,2	374	26	21.4	437.1	- 37.1	15300	14610	1.04
3,4	360	- 4	59.0	565.7	-209.7	16700	14080	1.19
5,6	341	- 25	28.1	487.0	-171.0	14470	13450	1.07
7,8	320	- 37	62.0	450.8	-166.8	13310	12120	1.10
9,10	292	- 36	24.4	377.0	-121.0	11310	9980	1.14
11,12	163	- 35	78.0	172.4	- 9.4	5614	5780	.97
13,14	- 8	- 35						
15				5.0		141	387	.36
16				-16.0		- 452	4365	-.10
17				107.0		3026	7475	.40
18				312.0		8823	9712	.91
19				332.0		9389	10420	.89
20,21				944.0		28600	28870	.99
22,23				960.0		29090	28870	1.01
24,25				977.0		29600	28870	1.02
26,27				972.0		29450	28870	1.02
28,29				976.0		29570	28870	1.02

TABLE IV

Observed Strains and Stress Concentration Factor for Each Gage Location
Stiffening Ring Breadth = 3/4"

Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1 (calc) psi	Stress conc. factor
τ/σ = 0.20, Load 38005 Lbs.								
1,2	517	-214	10.8	543.5	-392.5	14210	15540	.91
3,4	512	-125	80.3	531.1	-143.1	16200	15190	1.08
5,6	507	- 43	5.4	511.9	- 47.9	16474	14710	1.12
7,8	497	- 21	88.5	497.4	- 21.4	16250	13840	1.17
9,10	473	- 82	0.0	468.0	- 87.0	14650	12590	1.16
11,12	395	-232	83.6	402.0	-240.0	10980	10450	1.05
13,14	290	-269	36.2	934.8	-913.8	22160	8123	2.73
15				58.0		1640	8276	.20
16				523.0		14790	9880	1.50
17				696.0		19680	11390	1.73
18				650.0		18380	12670	1.45
19				329.0		9300	13150	.71
20,21				751.0		22750	23250	.98
22,23				701.0		21240	22750	.94
24,25				676.0		20480	22290	.92
26,27				663.0		20090	21970	.91
28,29				664.0		20120	21490	.93
τ/σ = 0.35, Load 39955 Lbs.								
1,2	487	-270	12.1	522.7	-306.7	14350	15600	.92
3,4	492	-148	77.7	523.9	-179.9	15600	15250	1.02
5,6	491	- 35	14.2	527.0	- 71.0	16752	14890	1.12
7,8	490	- 4	74.7	530.0	- 44.0	17110	14330	1.19
9,10	485	- 70	1.5	484.4	- 70.4	15350	13570	1.13
11,12	445	-290	84.2	451.8	-297.8	12088	12190	.98
13,14	394	-379	31.9	882.9	-867.9	20880	10700	1.95
15				87.0		2460	10800	.23
16				710.0		20080	11880	1.69
17				858.0		24260	12860	1.89
18				658.0		18600	13710	1.36
19				227.0		6420	14040	.46
20,21				555.0		16820	17500	.96
22,23				476.0		14420	16841	.86
24,25				443.0		13420	16225	.83
26,27				429.0		13000	15800	.82
28,29				430.0		13030	15170	.86

TABLE IV (cont'd)

τ/σ = 0.50, Load 39995 Lbs.								
Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1 (calc) psi	Stress conc. factor
1,2	498	-322	13.5	548.0	-373.0	14560	15320	.95
3,4	472	-164	75.1	520.0	-212.0	15150	15050	1.01
5,6	463	- 22	23.0	568.0	-128.0	17560	14740	1.19
7,8	469	9	60.9	675.0	-197.0	20440	14365	1.42
9,10	472	- 54	3.0	473.4	- 55.4	15110	13830	1.09
11,12	462	-308	84.7	546.0	-238.0	15780	12870	1.23
13,14	443	-426	27.6	769.8	-752.8	18250	11870	1.54
15				108.0		3054	11970	.25
16				801.0		22650	12710	1.78
17				922.0		26070	13400	1.95
18				641.0		18130	14000	1.29
19				158.0		4468	14290	.31
20,21				426.0		12900	13600	.95
22,23				346.0		10480	12880	.81
24,25				294.0		8910	12190	.73
26,27				278.0		8423	11720	.72
28,29				279.0		8454	11020	.76
Pure Bending, Load 43980 Lbs.								
1,2	408	- 10	21.4	483.8	- 85.8	15180	14610	1.04
3,4	391	- 31	59.0	629.4	-269.4	18240	14080	1.30
5,6	362	- 50	28.1	526.3	-214.3	15360	13450	1.14
7,8	330	- 55	62.0	470.1	-196.1	13670	12120	1.13
9,10	279	- 56	24.4	365.5	-141.5	10730	9980	1.08
11,12	130	- 36	78.0	137.8	- 43.8	4140	5780	.71
13,14	-28	- 19						
15				- 2.0		- 56	387	-.14
16				-41.0		-1160	4365	-.27
17				107.0		3026	7475	.40
18				383.0		10831	9712	1.12
19				409.0		11560	10420	1.11
20,21				931.0		28210	28870	.98
22,23				950.0		28780	28870	.99
24,25				964.0		29210	28870	1.01
26,27				965.0		29240	28870	1.01
28,29				966.0		29270	28870	1.01

TABLE V

Observed Strains and Stress Concentration Factor for Each Gage Location
Stiffening Ring Breadth = 7/16"

Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1(calc) psi	Stress conc. factor
t/c = 0.20, Load 37950 Lbs.								
1,2	525	-220	10.8	553.1	-248.1	15920	15540	1.02
3,4	550	-138	80.3	570.7	-158.7	17360	15190	1.14
5,6	565	- 62	5.4	570.6	- 67.6	18230	14710	1.24
7,8	558	- 34	88.5	558.4	- 34.4	18140	13840	1.31
9,10	524	- 40	0.0	524.0	- 40.0	16950	12590	1.35
11,12	402	-162	83.6	409.2	-169.2	11910	10450	1.14
13,14	272	-252	36.2	876.4	-856.4	20770	8123	2.56
15				52.0		1470	8276	.18
16				577.0		16330	9880	1.65
17				837.0		23700	11390	2.08
18				702.0		19900	12670	1.57
19				347.0		9820	13150	.75
20,21				753.0		22820	23250	.98
22,23				700.0		21210	22750	.93
24,25				670.0		20300	22290	.91
26,27				657.0		19910	21970	.91
28,29				660.0		20000	21490	.93
t/c = 0.35, Load 36885 Lbs.								
1,2	451	-279	12.1	321.9	-149.9	9210	14390	.64
3,4	487	-145	77.7	518.5	-176.5	15460	14060	1.10
5,6	520	- 22	14.2	557.1	- 59.1	17860	13730	1.30
7,8	528	26	74.7	568.6	- 14.6	18670	13210	1.41
9,10	517	16	1.5	517.4	15.6	17260	12510	1.38
11,12	440	-184	84.2	446.6	-190.6	12940	11240	1.15
13,14	350	-337	31.9	784.5	-771.5	18550	9866	1.88
15				74.0		2092	9963	.21
16				737.0		20840	10950	1.90
17				970.0		27431	11860	2.32
18				710.0		20080	12641	1.59
19				235.0		6645	12950	.51
20,21				520.0		15760	16130	.98
22,23				450.0		13630	15530	.88
24,25				407.0		12330	14960	.83
26,27				390.0		11820	14670	.81
28,29				395.0		11970	13990	.85

TABLE V (cont'd)

Gage No.	ϵ_x x10^6	ϵ_y x10^6	θ degrees	ϵ_1 x10^6	ϵ_2 x10^6	σ_1 psi	σ_1(calc.) psi	Stress conc. factor
τ/σ = 0.50, Load 34750 Lbs.								
1,2	395	-281	13.5	436.3	-322.3	11340	13320	.86
3,4	437	-142	75.1	481.1	-186.1	14130	13090	1.08
5,6	477	- 11	23.0	584.3	-118.3	18190	12820	1.42
7,8	492	42	60.9	694.0	-160.0	21424	12490	1.72
9,10	495	43	3.0	496.2	41.8	16820	12030	1.40
11,12	440	-160	84.7	445.2	-165.2	13140	11190	1.08
13,14	376	-362	27.6	653.6	-639.6	15490	10320	1.50
15				91.0		2573	10390	.25
16				793.0		22420	11040	2.03
17				998.0		28220	11640	2.42
18				667.0		18860	12170	1.55
19				165.0		4660	12410	.37
20,21				379.0		11480	11820	.97
22,23				301.0		9120	11190	.82
24,25				254.0		7696	10590	.73
26,27				237.0		7181	10186	.71
28,29				241.0		7300	9580	.76
Pure Bending, Load 43925 Lbs.								
1,2	445	- 35	21.4	532.1	-122.1	16430	14610	1.12
3,4	376	- 45	59.0	551.3	-260.3	15740	14080	1.12
5,6	294	- 50	28.1	431.2	-187.2	12500	13450	.93
7,8	290	- 50	62.0	414.9	-174.9	12050	12120	.99
9,10	281	- 46	24.4	365.7	-130.7	10840	9980	1.09
11,12	178	- 22	78.0	187.5	- 31.5	5901	5780	1.02
13,14								
15				0.0		0	387	.00
16				-79.0		-2230	4365	-.51
17				112.0		3170	7475	.42
18				412.0		11650	9712	1.20
19				442.0		12500	10420	1.20
20,21				946.0		28660	28870	.99
22,23				960.0		29080	28870	1.01
24,25				977.0		29600	28870	1.03
26,27				976.0		29570	28870	1.02
28,29				974.0		29510	28870	1.02

FIGURE XV

STRESSCOAT CRACKS
PURE BENDING

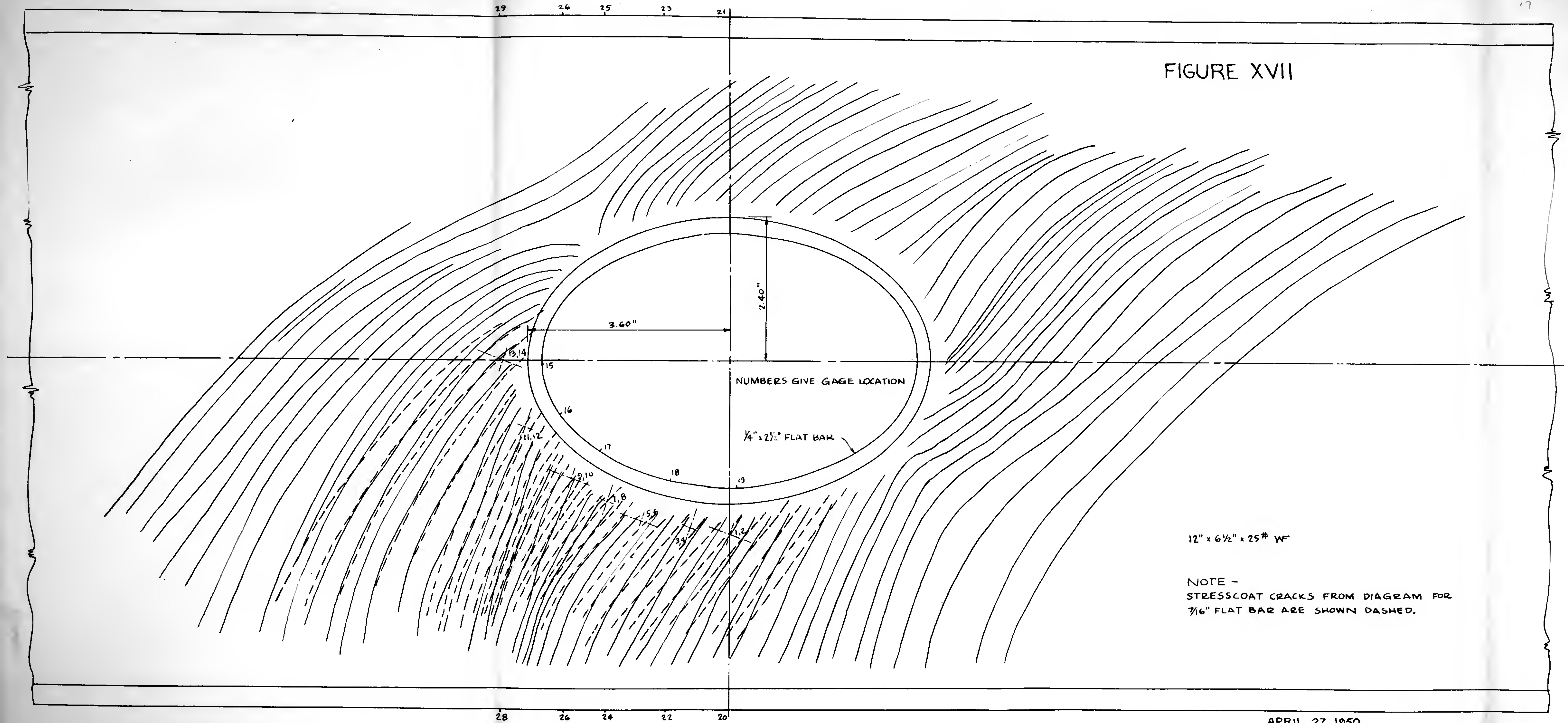
APRIL 27, 1950

FIGURE XVI

STRESSCOAT CRACKS

T/δ • .2

APRIL 27, 1950
A.H.S. J.A.G.



STRESSCOAT CRACKS

r/b = .5

APRIL 27, 1950

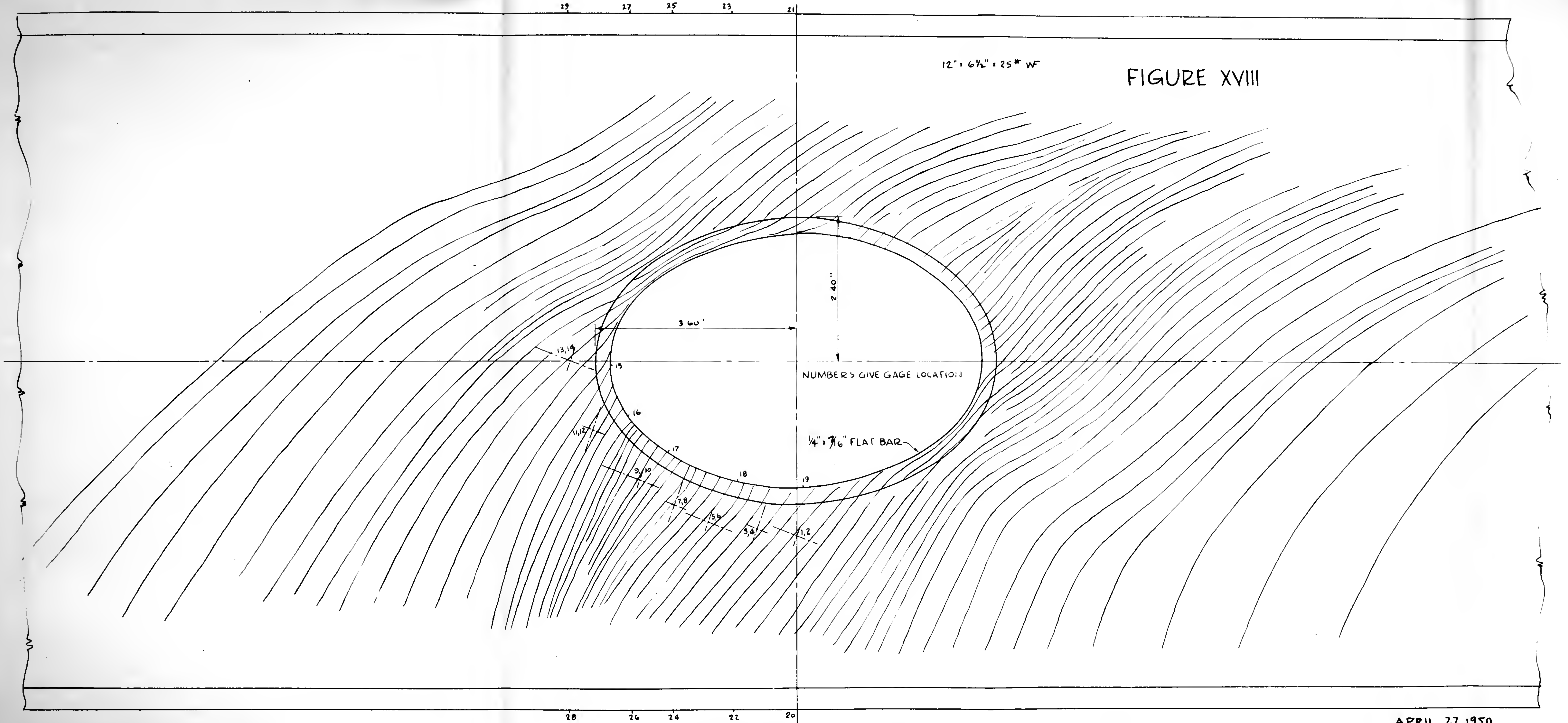


FIGURE XVIII

STRESSCOAT CRACKS

$T/\sigma = .5$

APRIL 27, 1950
A.W.S. S.G.E.

Figure XIX

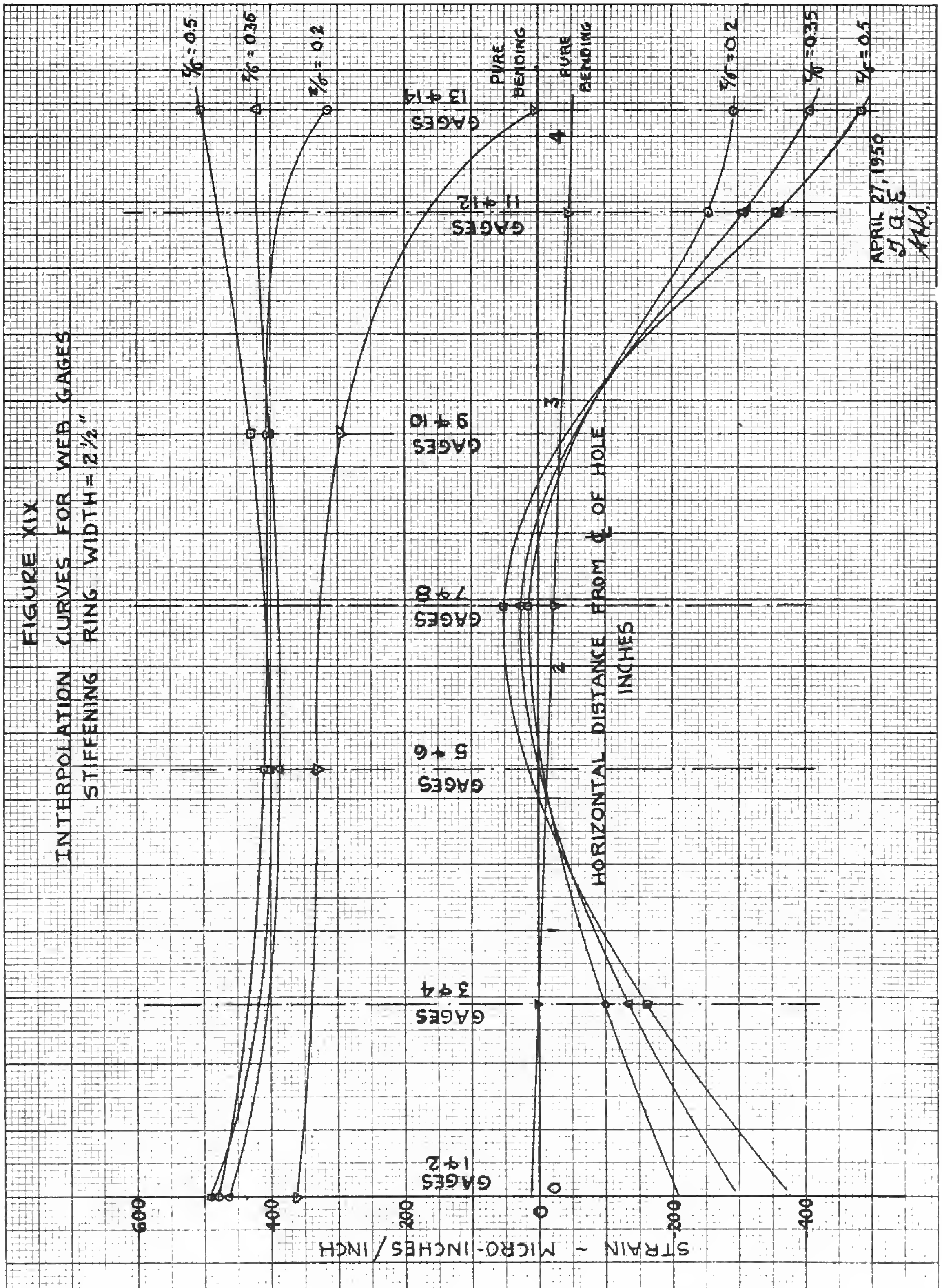


FIGURE XIX
INTERPOLATION CURVES FOR WEB GAGES
STIFFENING RING WIDTH = 2½"
HORIZONTAL DISTANCE FROM ℄ OF HOLE
INCHES
STRAIN ~ MICRO-INCHES/INCH
GAGES 1 & 2
GAGES 3 & 4
GAGES 5 & 6
GAGES 7 & 8
GAGES 9 & 10
GAGES 11 & 12
GAGES 13 & 14
PURE BENDING
PURE BENDING
APRIL 27, 1956

Figure XX

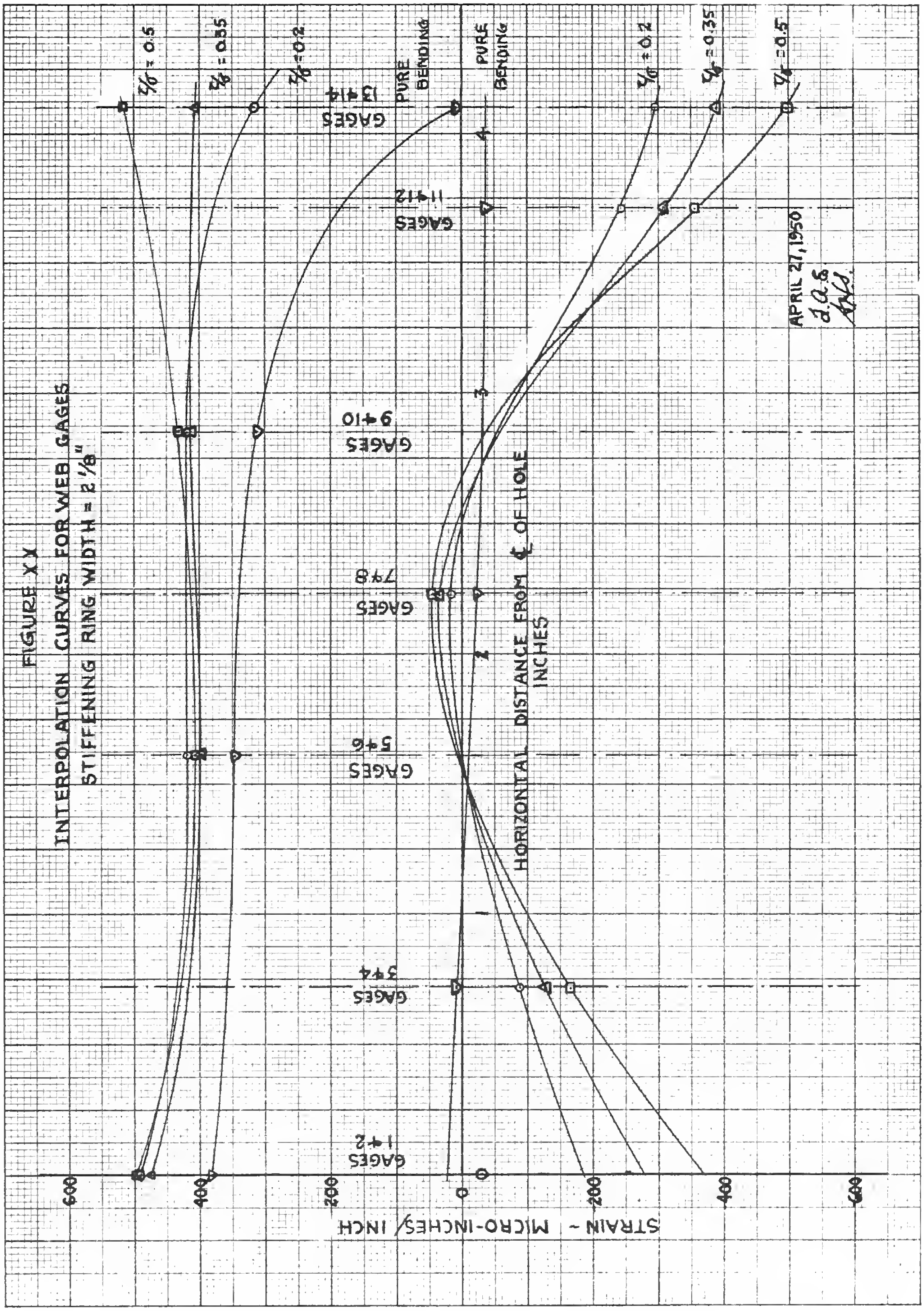


FIGURE XX
INTERPOLATION CURVES FOR WEB GAGES
STIFFENING RING WIDTH = 2 1/8"
HORIZONTAL DISTANCE FROM ℄ OF HOLE
INCHES
STRAIN ~ MICRO-INCHES/ INCH
GAGES 1+2
GAGES 3+4
GAGES 5+6
GAGES 7+8
GAGES 9+10
GAGES 11+12
GAGES 13+14
PURE BENDING
PURE BENDING
r/b = 0.5
r/b = 0.35
r/b = 0.2
APRIL 27, 1950

Figure XXI

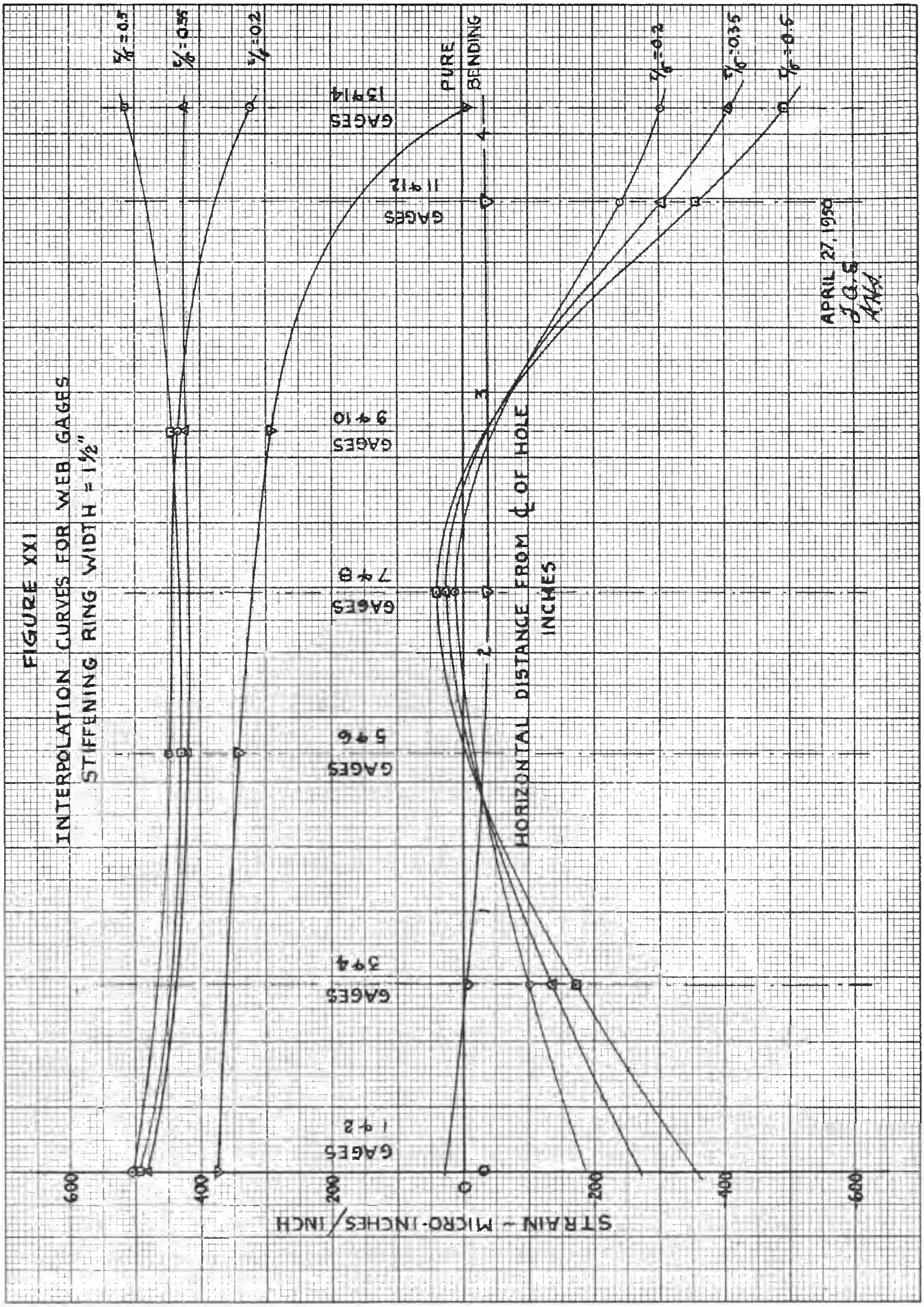


FIGURE XXI
INTERPOLATION CURVES FOR WEB GAGES
STIFFENING RING WIDTH = 1½"
HORIZONTAL DISTANCE FROM ℄ OF HOLE
INCHES
STRAIN ~ MICRO-INCHES/INCH
GAGES 1 & 2
GAGES 3 & 4
GAGES 5 & 6
GAGES 7 & 8
GAGES 9 & 10
GAGES 11 & 12
GAGES 13 & 14
PURE BENDING
APRIL 27, 1950

Figure XXII

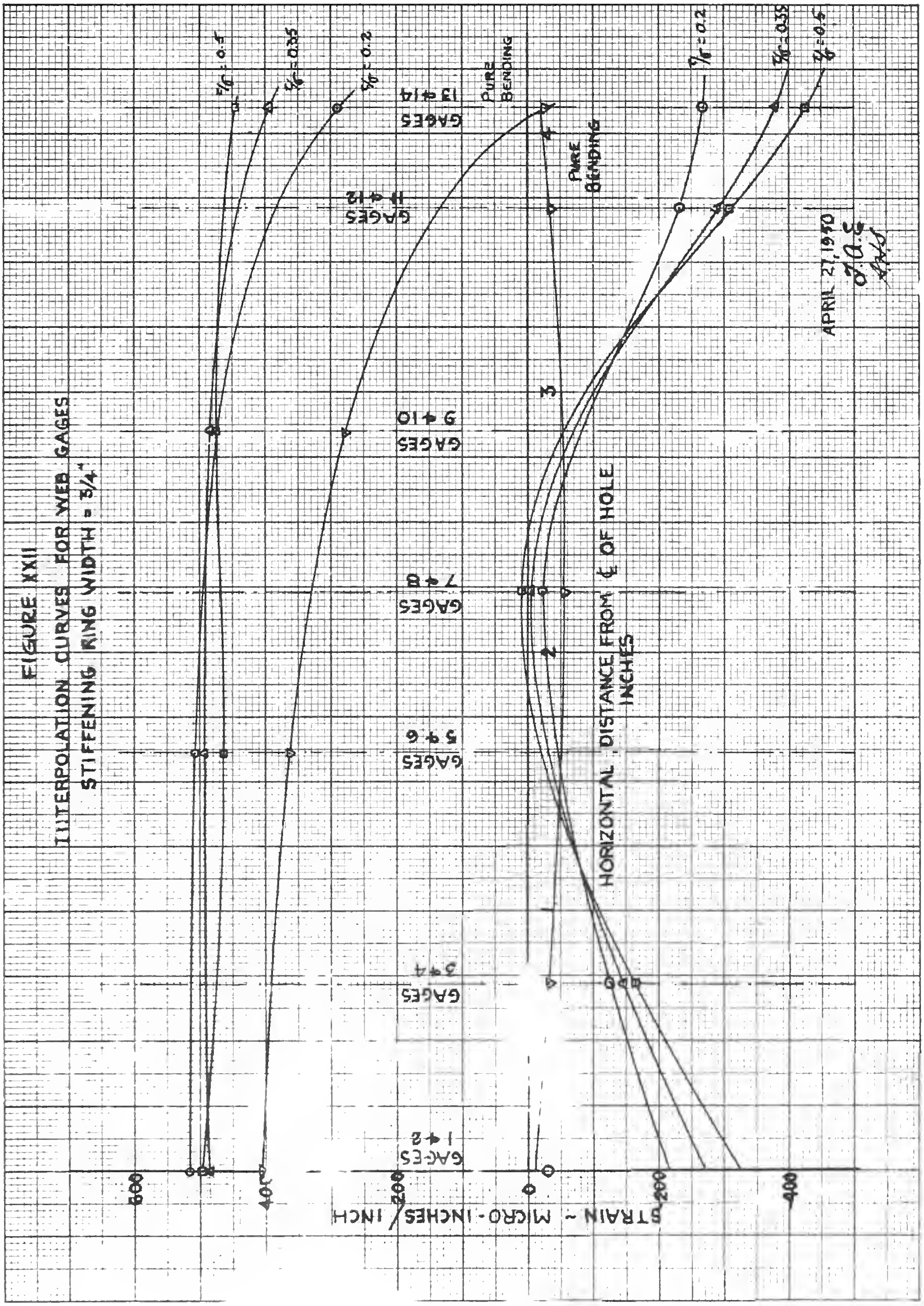


FIGURE XXII
INTERPOLATION CURVES FOR WEB GAGES
STIFFENING RING WIDTH = 3/4"
HORIZONTAL DISTANCE FROM ℄ OF HOLE
INCHES
STRAIN ~ MICRO-INCHES/INCH
GAGES 1 & 2
GAGES 3 & 4
GAGES 5 & 6
GAGES 7 & 8
GAGES 9 & 10
GAGES 11 & 12
GAGES 13 & 14
PURE BENDING
PURE BENDING
APRIL 27, 1950

Figure XXIII

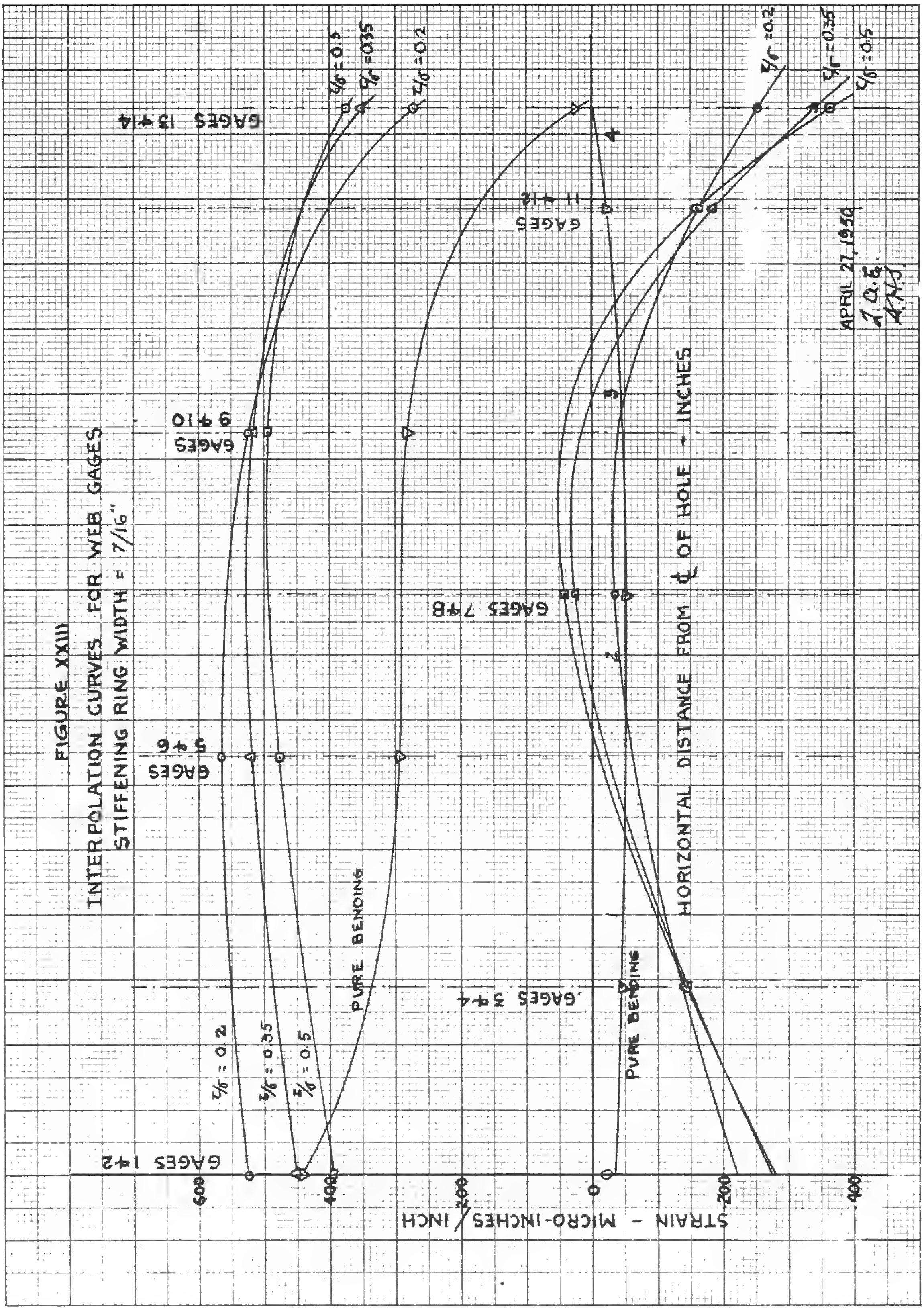
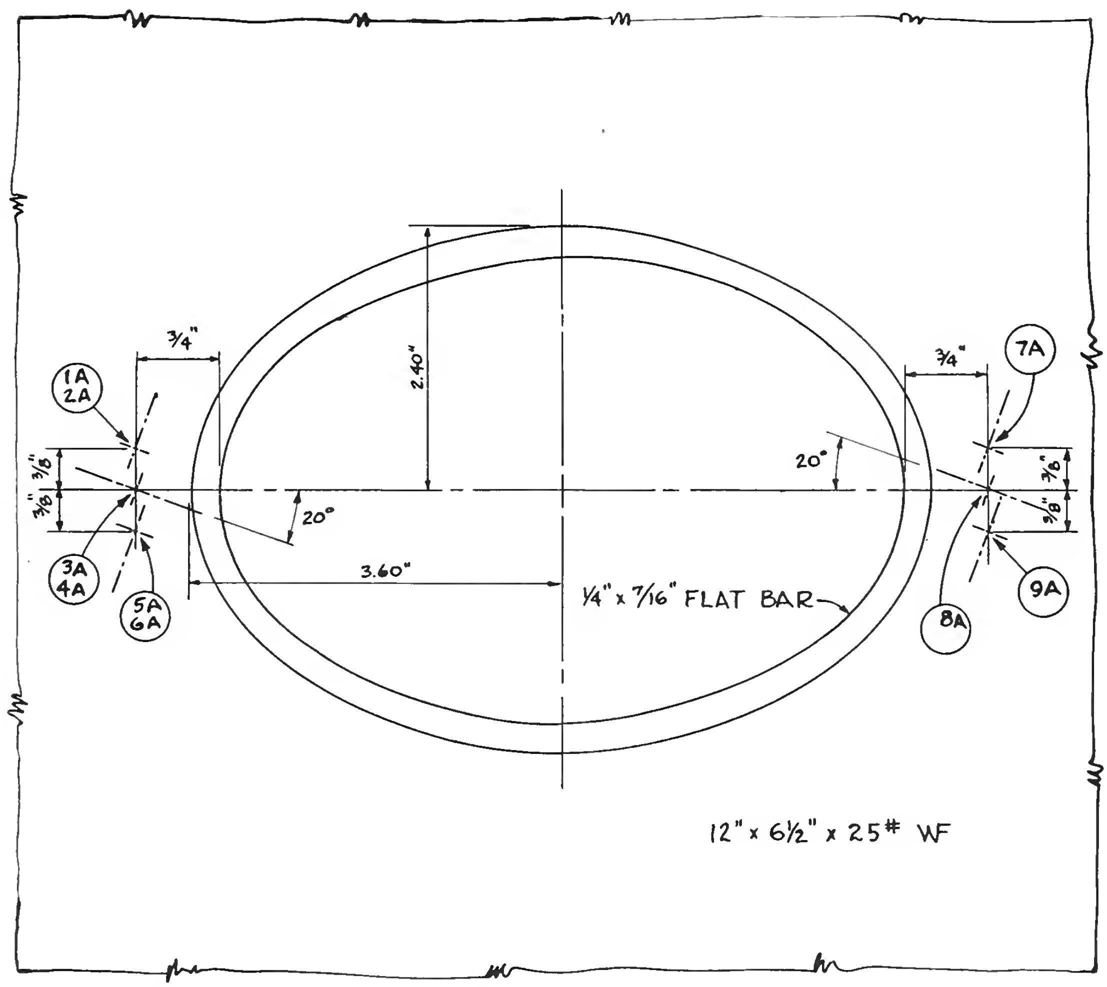


FIGURE XXIV



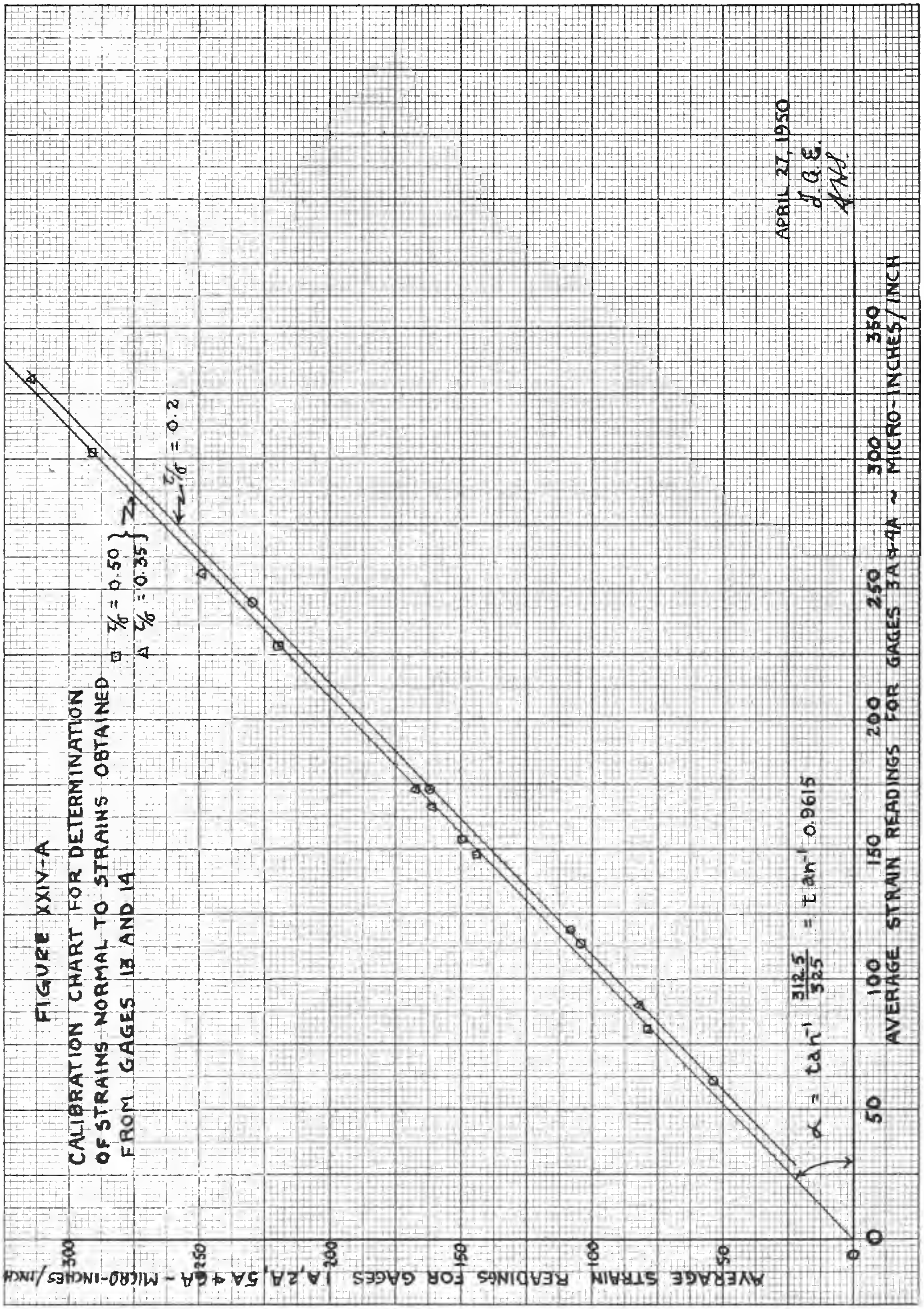
LOCATION OF SUPPLEMENTARY "A" GAGES
ON WEB
GAGES 1A, 3A, 5A, 7A, 8A, 9A NEAR SIDE

GAGES 2A, 4A, 6A FAR SIDE

GAGES 3A, 4A SAME LOCATION AS GAGES 13, 14.

APRIL 27, 1950
A.H.S. J.Q.E.

Figure XXIV -A



APPENDIX C

SAMPLE CALCULATIONS

In this section are examples of the calculations for gages on the web, the stiffening ring, and the flanges. Theoretical stress based upon the intact beam is calculated for each example of gage location. The method of deriving the stress from the strain gage readings is given. While the method is quite simple for the stiffening ring and flange gages, consisting merely of multiplying the observed strain by the modulus of the material, the calculation in the case of the web gages is more complicated and will be explained here.

As stated in Appendix B, Details of Procedure, it was not practicable to use rosette gages, because their size conflicted with the desire to locate the web gages as close as possible to the stiffening ring. As is seen diagrammatically from Mohr's Circle, if two stresses normal to each other

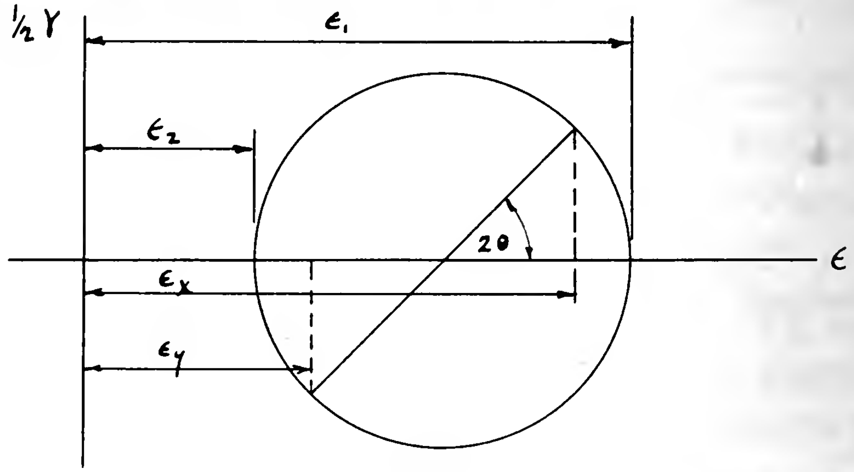


Figure XLIV - Mohr's Circle for Strain

can be measured at a given point, the principal strains can be obtained if θ is known, according to the relations

$$\epsilon_1 = \frac{\epsilon_x + \epsilon_y}{2} + \frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta \qquad (1)$$

$$\epsilon_2 = \frac{\epsilon_x + \epsilon_y}{2} - \frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta \qquad (2)$$

θ is determined by the stresscoat cracks which are the orthogonal trajectories of the principal tensile strains. To determine the values of θ for $\tau/\sigma = 0.35$, linear interpolation between the values for 0.20 and 0.50 was used. It should be noted here that θ is assumed to remain constant for various breadths of stiffening ring. As a check upon this assumption, at the conclusion of the strain measurement tests a stresscoat diagram was obtained for the 7/16" stiffening ring at $\tau/\sigma = 0.50$. This is compared, in Figure XVII, with the original for the 2½" ring. Although there is some deviation between the lines, those in the vicinity of gages 13 and 14 are essentially parallel. This pair of gages is the only pair at which a high stress concentration is indicated, and the above assumption is true for them. The order of magnitude of the results for the other web gages is not altered by the fact that the assumption for them is not strictly correct. Hence in the calculations, θ varies only with mode of loading.

With gages 1 and 2, 5 and 6, 9 and 10, and 13 and 14 oriented with their axis 20° below the horizontal, and gages 3 and 4, 7 and 8, and 11

and 12 at 110° below the horizontal, a plot of strains vs. longitudinal distance along the beam could be made for the two sets of gages which would be a fair curve. These are the Interpolation curves, Figures XIX-XXIII. ϵ_x is given by the gages at 20°, and ϵ_y by the gages at 110°. Thus from these charts, the strain at right angles to any gage can be determined.

Having determined ϵ_1 and ϵ_2, the principal stress, σ_1, is obtained from the formula

$$\sigma_1 = \frac{(\epsilon_1 + \mu \epsilon_2)E}{1 - \mu^2} \tag{3}$$

in which, from the results of the tensile test specimen, Young's modulus

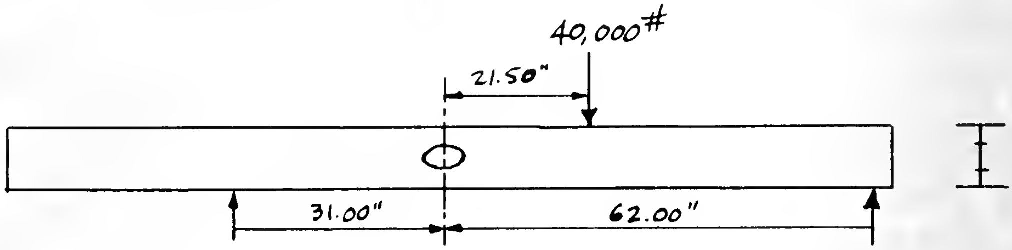
$$E = 30.3 \times 10^6$$

and Poisson's ratio is assumed to be

$$\mu = .29$$

A. Web Gage Calculation

(1) Stress for the intact beam for gages 3 and 4 under loading condition $\tau/\sigma = 0.35$



Specifications of the intact beam:

Dimensions 12" x $6\frac{1}{2}$" x 25# WF

$I = 183.4$ ins.^{4}

Depth $C = 11.87$"

Web thickness $b = 0.24$"

Average flange thickness 0.355"

Section Modulus $S = 30.9$ ins.^{3}

$$M_{R_2} = 0 = 93\,R_1 - 1620{,}000$$

$$R_1 = 17420\ \#$$

$$\text{Lever} = 31.00 - 0.72$$

$$= 30.28"$$

$$\text{Moment} = 17420 \times 30.28$$

$$= 540{,}000 \text{ in. lbs.}$$

$$y = 2.90"$$

$$\sigma = My/I = \frac{540000 \times 2.90}{183.4}$$

$$= 8332 \text{ psi}$$

$$\text{Longitudinal Shearing Stress} = \frac{R_1\,Q}{I\,b} = \tau_L$$

$$= \frac{17420 \times 25.98}{183.4 \times .24}$$

$$= 10270 \text{ psi.}$$

σ_1 = maximum principal stress

$$\sigma_1 = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau_L^{\,2}}$$

$$= 4166 + 10^3\sqrt{17.36 + 105.47}$$

$$= 15{,}250 \text{ psi.}$$

(2) Derived Stress From Gages 3 and 4

τ/σ = 0.35, Stiffening Ring $1\frac{1}{2}$"

$$\epsilon_1 = \frac{\epsilon_x + \epsilon_y}{2} + \frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta$$

$$\epsilon_2 = \frac{\epsilon_x + \epsilon_y}{2} - \frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta$$

ϵ_x = value obtained from interpolation curves, Figure XXI, upper curves, for τ/σ = 0.35, at line marked "gages 3 and 4."

ϵ_y = value obtained from interpolation curves, Figure XXI, lower curves for τ/σ = 0.35, at line marked "gages 3 and 4."

ϵ_x = 423 micro-inches per inch

ϵ_y = -137 micro-inches per inch

(These values appear also in Table III)

$$\frac{\epsilon_x + \epsilon_y}{2} = 143$$

$$\frac{\epsilon_x - \epsilon_y}{2} = 280$$

$$2\theta = 155.4^\circ$$

$\sec 2\theta = -1.0998$

$$\frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta = -307.9$$

$$\epsilon_1 = 143 + (-307.9)$$

$$= -164.9 \text{ micro-inc. per in.}$$

$$\epsilon_2 = 143 - (-307.9)$$

$$= 450.9 \text{ micro-in. per in.}$$

$$\sigma_1 = \frac{(\epsilon_{max} + \mu\,\epsilon_{min})\,E}{1 - \mu^2}$$

$$\mu = .29$$

$$\frac{E}{1 - \mu^2} = 33.082 \times 10^6$$

$$\epsilon_{max} + \mu\,\epsilon_{min} = 403.1$$

$$\sigma_1 = 403.1 \times 33.082$$

$$= 13330 \text{ psi}$$

(3) Calculation of stress concentration factor:

Stress concentration factor is defined as the ratio of the derived stress to the calculated stress.

$$\text{Factor} = \frac{13330}{15250}$$

$$= 0.87$$

B. Stiffening Ring Gage Calculation

(1) Derived Stress

$\tau/\sigma = 0.35$, Stifening Ring $1\frac{1}{2}$"

Gage No. 17

Load 39,945 Lbs.

ϵ_1 = gage reading

= 694 micro-inches per inch

$E = 28.28 \times 10^6$ psi

$\sigma = E\ \epsilon_1$

$= 28.28 \times 10^6 \times 694 \times 10^{-6}$

= 19630 psi.

(2) Calculated stress is obtained in a manner similar to the web gage.

Calculated stress = 12860 psi.

(3) Stress concentration factor = $\frac{19630}{12860}$

Factor = 1.53

C. Flange Gage Calculation

(1) $\tau/\sigma = 0.35$, Stiffening Ring $1\frac{1}{2}$"

Gage Nos. 20 and 21

Load 39,945 Lbs.

ϵ_1 = gage reading (taken as the average of gages 20 and 21)

= 564 micro-inches per inch

E = 30.3×10^6 psi.

$\sigma = E\ \epsilon_1$

$= 30.3 \times 10^6 \times 564 \times 10^{-6}$

= 17090 psi.

(2) Calculated Stress

Let σ_c = calculated stress

M = Bending moment

= Lever x R_1

= 31.00 x 174 20

= 540,000 inch pounds

S = 30.9 ins.^{3}

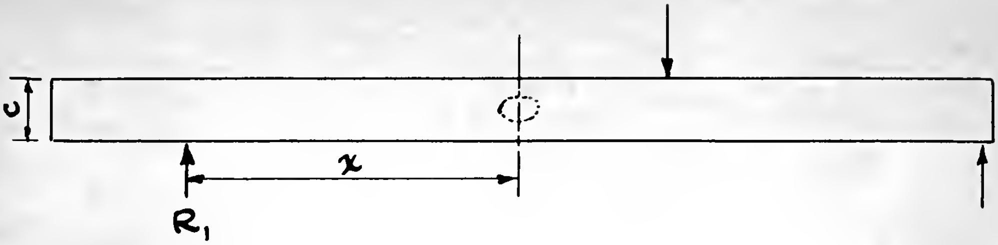
$\sigma_c = \frac{M}{S}$

$= \frac{540,000}{30.9}$

= 17500 psi.

(3) Stress Concentration Factor = 0.98

D. Calculation for the Loading Condition



$$\sigma = \frac{Mc}{2\,I}$$

$$\tau = \frac{V}{t\,c} = \frac{R_1}{t\,c}$$

$$\tau/\sigma = \frac{2\,R\,I}{M\,c^2 t}$$

but $\quad M = R_1 x$

hence $\quad \tau/\sigma = \dfrac{2\,I}{x\,t\,c^2}$

for any beam $\quad \dfrac{2\,I}{t\,c^2} \quad = \quad$ a constant, K

then $\quad \tau/\sigma = \dfrac{K}{x}$

$$x = K\left(\frac{1}{\tau/\sigma}\right)$$

and K for the beam $= \dfrac{2 \times 183.4}{.24\,(11.87)^2}$

$$= 10.85$$

Hence x for τ/σ = .35 becomes

$$x_{.35} = \frac{10.85}{.35}$$

$$= 31.00''$$

E. Stress Concentration Factor At Gage 8A

Using Values from Figure XXV

(1) $\tau/\sigma = 0.50$

ϵ_x = 345 micro-inches per inch (gage 8A)

ϵ_y = -315 micro-inches per inch (average, gages 7A and 9A)

$$\frac{\epsilon_x + \epsilon_y}{2} = 15 = D$$

$$\frac{\epsilon_x - \epsilon_y}{2} = 330 = E_1$$

$$2\theta = 49.0^\circ$$

$$\text{Sec } 2\theta = 1.5243$$

$$E_1 \text{ Sec } 2\theta = 503.0 = H$$

$$\epsilon_1 = D + H = 545.0$$

$$\epsilon_2 = D - H = -488.0$$

$$\sigma_1 = \frac{(\epsilon_1 + \mu \epsilon_2) E}{1 - \mu^2}$$

$$\mu = .29$$

$$E = 30.3 \times 10^6$$

$$\frac{E}{1 - \mu^2} = 33.082 \times 10^6$$

$$\epsilon_1 + \mu \epsilon_2 = 545.0 - 141.5$$

$$= 403.5 \text{ micro-inches per in.}$$

$$\sigma_1 = 403.5 \times 33.082$$

$$= 13350 \text{ psi}$$

Calculated Stress σ_c = 10260 psi.

Stress Concentration Factor = σ_1 / σ_c

= 1.30

(2) τ / σ = 0.20

ϵ_x = 293 micro-inches per inch (Gage 8A)

ϵ_y = -248 micro-inches per inch (average, gages 7A and 9A)

$$\frac{\epsilon_x + \epsilon_y}{2} = 22.5 = D$$

$$\frac{\epsilon_x - \epsilon_y}{2} = 270 = E_1$$

$$2\theta = 69.0^\circ$$

$$\text{Sec } 2\theta = 2.790$$

$$\frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta = 754.7 = H$$

$$\epsilon_1 = D + H = 777.2$$

$$\epsilon_2 = D - H = -732.2$$

$$\sigma_1 = \frac{(\epsilon_1 + \mu \epsilon_2) E}{1 - \mu^2}$$

$$\mu = .29$$

$$\frac{E}{1 - \mu^2} = 33.082 \times 10^6 \quad \text{where } E = 30.3 \times 10^6$$

$$\epsilon_1 + \mu \epsilon_2 = 777.2 + .29(-732.2)$$

$$= 564.9 \text{ micro-inches per inch}$$

$$\sigma_1 = 564.9 \times 33.082$$

$$= 18{,}690 \text{ psi.}$$

Calculated stress σ_c ; 8120 psi

$$\text{Stress Concentration Factor} = \frac{\sigma_1}{\sigma_c}$$

$$= 2.30$$

TABLE XII

VALUES OF STRAINS NORMAL TO STRAINS FOR GAGES 13 AND 14 FOR VARIOUS BREADTHS OF STIFFENING RING

	$\tau/\sigma = 0.20$			$\tau/\sigma = 0.35$			$\tau/\sigma = 0.50$		
Stiffening Ring Breadth	x $\times 10^6$	K	y $\times 10^6$	x $\times 10^6$	K	y $\times 10^6$	x $\times 10^6$	K	y $\times 10^6$
$2\frac{1}{2}$"	315	0.9615	-293	425	0.9615	-409	505	.9615	-486
2 1/8"	317	↓	-295	405	↓	-389	518	↓	-498
$1\frac{1}{2}$"	323	↓	-301	423	↓	-407	515	↓	-495
3/4"	290	↓	-269	394	↓	-379	443	↓	-426
7/16"	272	↓	-252	350	↓	-337	376	↓	-362

K = Slope of Strain vs. Strain line
from Figure XXIV-A

$\epsilon_y = -K\,\epsilon_x$ for $\tau/\sigma = 0.35$ and 0.50

$\epsilon_y = -K\,\epsilon_x + 10$ for $\tau/\sigma = 0.20$

APPENDIX D

ORIGINAL DATA

Stiffening Ring Breadth = 2½" τ/δ = 0.2   Load Increasing   March 22, 1950

Load		0	9100		18000		27000		37740	
Gage Factor	Gage No.	Indicator Reading		Strain Increment $x10^6$	Indicator Reading	Strain Increment $x10^6$	Indicator Reading	Strain Increment $x10^6$	Indicator Reading	Strain Increment $x10^6$
1.80	1	4898	5000	102	5110	110	5210	110	5338	118
	2	5130	5255	125	5378	123	5500	122	5650	150
	3	4546	4544	- 02	4525	- 19	4507	- 18	4490	- 17
	4	5360	5312	- 48	5285	- 27	5255	- 30	5220	- 30
	5	4655	4750	95	4845	95	4938	93	5050	112
	6	4430	4533	103	4634	101	4733	99	4855	122
	7	5510	5533	23	5543	10	5552	09	5565	13
	8	5342	5322	- 20	5320	- 02	5313	- 07	5310	03
	9	5483	5580	97	5680	100	5780	100	5900	120
	10	5044	5139	95	5233	94	5325	92	5440	115
1.82	11	6490	6440	- 50	6379	- 61	6315	- 64	6242	- 73
	12	7295	7220	- 75	7163	- 57	7104	- 59	7033	- 71
	13	6813	6885	72	6958	73	7030	72	7120	90
	14	6975	7055	80	7132	77	7208	76	7300	92
	15	6524	6540	16	6554	14	6568	14	6586	18
	16	6325	6427	102	6525	98	6623	98	6743	120
	17	5912	6042	130	6170	128	6295	125	6450	155
	18	6140	6247	107	6352	105	6456	104	6585	129
	19	5840	5893	53	5947	54	6000	53	6070	70
1.76	20	7105	7280	175	7455	175	7625	170	7833	208
	21	7328	7148	-170	6974	-174	6800	-174	6590	-210
	22	6575	6737	162	6897	170	7055	158	7248	193
	23	5600	5414	-186	5245	-169	5080	-165	4880	-200
	24	7105	7265	160	7425	160	7587	162	7780	193
	25	6250	6080	-170	5920	-160	5763	-157	5573	-190
	26	6430	6587	157	6743	156	6896	153	7084	188
	27	6374	6220	-154	6063	-157	5905	-158	5720	-185
	28	7054	7220	166	7365	145	7520	155	7704	184
	29	6674	6510	-164	6352	-158	6192	-160	6003	-189

Table VI. Original Data

Stiffening Ring Breadth = $2\frac{1}{2}$"			t/s = .2		Load Decreasing			March 22, 1950	
Load		27000		18000		9100		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5223	-115	5122	-101	5010	-112	4900	02
↓	2	5510	-140	5390	-120	5261	-129	5132	02
	3	4510	20	4530	20	4550	20	4551	05
	4	5260	40	5292	32	5320	28	5367	07
	5	4950	-100	4860	- 90	4759	-101	4660	05
	6	4745	-110	4647	- 98	4540	-107	4434	04
	7	5552	- 13	5542	- 10	5540	- 02	5515	05
	8	5316	6	5322	6	5325	3	5348	06
	9	5792	-108	5697	- 95	5590	-107	5485	02
	10	5340	-100	5249	- 91	5147	-102	5047	03
1.82	11	6314	82	6375	61	6444	69	6497	07
↓	12	7102	69	7165	63	7224	59	7302	07
	13	7036	- 93	6965	- 71	6890	- 75	6818	05
	14	7212	- 88	7136	- 75	7060	- 76	6980	05
	15	6566	- 20	6554	- 12	6540	- 14	6530	06
	16	6625	-118	6530	- 95	6430	-100	6330	05
	17	6307	-143	6183	-124	6050	-133	5920	08
	18	6475	-110	6372	-103	6257	-115	6145	05
	19	6020	- 50	5967	- 53	5904	- 63	5845	05
1.76	20	7645	-188	7475	-170	7290	-185	7104	- 01
↓	21	6800	173	6973	173	7154	181	7335	07
	22	7076	-172	6920	-156	6747	-173	6576	01
	23	5075	195	5246	171	5420	174	5598	- 02
	24	7610	-170	7453	-157	7278	-175	7107	02
	25	5760	187	5920	160	6082	162	6249	- 01
	26	6920	-164	6769	-151	6600	-169	6430	00
	27	5900	180	6060	160	6223	163	6386	12
	28	7540	-164	7390	-150	7225	-165	7060	06
	29	6190	187	6350	160	6515	165	6682	08

Table VI. Original Data

Stiffening Ring Breadth = $2\frac{1}{2}$" t/δ = .35   Load Increasing   March 22, 1950

Load		0	10000		20000		30000		40000	
Gage Factor	Gage No.	Indicator Reading	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80	1	4902	5000	98	5104	104	5209	105	5310	101
↓	2	5135	5268	133	5400	132	5528	126	5655	127
	3	4554	4555	1	4530	- 25	4504	- 26	4478	- 26
	4	5366	5292	- 74	5250	- 42	5210	- 40	5171	- 39
	5	4661	4749	88	4839	90	4929	90	5017	88
	6	4435	4543	108	4648	105	4751	103	4853	102
	7	5516	5568	52	5587	19	5609	22	5620	11
	8	5349	5310	- 39	5309	- 1	5305	- 04	5302	- 03
	9	5486	5584	102	5685	101	5787	102	5888	101
	10	5048	5150	102	5249	99	5348	99	5447	99
1.82	11	6497	6449	- 48	6370	- 79	6289	- 81	6210	- 79
↓	12	7302	7192	-110	7116	- 76	7041	- 75	6970	- 71
	13	6819	6913	94	7020	107	7122	102	7238	116
	14	6980	7090	110	7197	107	7299	102	7403	104
	15	6530	6549	19	6571	22	6592	21	6615	23
	16	6330	6476	146	6617	141	6754	137	6894	140
	17	5921	6086	165	6250	164	6410	160	6575	165
	18	6146	6258	112	6370	112	6480	110	6595	115
	19	5846	5882	36	5922	40	5960	38	6002	42
1.76	20	7103	7240	137	7375	135	7510	135	7647	137
↓	21	7334	7197	-137	7056	-141	6917	-139	6780	-137
	22	6576	6692	116	6810	118	6925	115	7041	116
	23	5598	5468	-130	5340	-128	5212	-128	5090	-122
	24	7106	7217	111	7329	112	7440	111	7551	111
	25	6248	6132	-116	6019	-113	5902	-117	5790	-112
	26	6429	6538	109	6644	94	6750	106	6859	109
	27	6385	6275	-110	6166	-109	6053	-113	5945	-108
	28	7059	7165	106	7270	105	7374	104	7480	106
	29	6681	6570	-111	6456	-114	6344	-112	6231	-113

Table VI. Original Data

Stiffening Ring Breadth = $2\frac{1}{2}$"		ν = .35		Load Decreasing				March 22, 1950	
Load		30000		20000		10000		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5211	- 99	5111	-100	5010	-101	4900	- 02
↓	2	5529	-126	5400	-129	5278	-122	5135	00
	3	4505	27	4532	27	4560	28	4554	00
	4	5210	39	5250	40	5297	47	5370	04
	5	4931	- 86	4848	- 83	4759	- 89	4660	- 01
	6	4751	-103	4651	-100	4550	-101	4435	00
	7	5600	20	5633	33	5569	36	5519	03
	8	5305	3	5305	0	5310	5	5349	00
	9	5791	- 97	5694	- 97	5596	- 98	5488	02
	10	5352	- 95	5256	- 96	5150	-106	5050	02
1.82	11	6282	72	6364	82	6449	85	6501	04
↓	12	7046	76	7117	71	7191	74	7301	- 01
	13	7127	-101	7021	-106	6918	-103	6820	01
	14	7299	-104	7194	-105	7091	-103	6980	00
	15	6590	- 25	6566	- 24	6545	- 21	6529	- 01
	16	6754	-140	6615	-137	6478	-137	6331	01
	17	6417	-158	6256	-161	6095	-161	5922	01
	18	6490	-105	6382	-108	6270	-112	6149	03
	19	5969	- 33	5933	- 36	5899	- 34	5848	02
1.76	20	7520	-127	7390	-130	7256	-133	7103	00
↓	21	6916	136	7053	137	7196	143	7340	06
	22	6935	-106	6823	-112	6710	-113	6576	00
	23	5212	122	5340	128	5469	129	5601	03
	24	7451	-100	7347	-104	7236	-111	7105	- 01
	25	5902	112	6017	115	6130	113	6253	05
	26	6762	- 97	6662	-100	6554	108	6430	01
	27	6051	106	6160	109	6276	116	6391	06
	28	7388	- 92	7289	- 99	7182	-107	7060	01
	29	6341	110	6453	112	6570	117	6688	07

Table VI. Original Data

Stiffening Ring Breadth = $2\frac{1}{2}$"		τ/σ = .5				Load Increasing			March 23, 1950	
Load		0	11000		22000		33000		44000	
Gage Factor	Gage No.	Indicator Reading		Strain Increment $x10^6$	Indicator Reading	Strain Increment $x10^6$	Indicator Reading	Strain Increment $x10^6$	Indicator Reading	Strain Increment $x10^6$
1.80	1	4892	4999	107	5102	103	5210	108	5315	105
	2	5125	5273	148	5412	139	5550	138	5683	133
	3	4540	4548	08	4510	- 38	4470	- 40	4440	- 30
	4	5350	5265	- 85	5221	- 44	5180	- 41	5128	- 52
	5	4651	4743	82	4833	90	4924	91	5013	89
	6	4426	4545	119	4655	110	4764	109	4872	108
	7	5506	5575	69	5592	17	5608	16	5632	24
	8	5330	5293	- 37	5300	07	5304	04	5300	04
	9	5479	5585	106	5690	115	5795	105	5900	105
	10	5040	5133	113	5256	103	5360	103	5470	110
1.82	11	6485	6430	- 55	6330	-100	6234	- 96	6127	-107
	12	7286	7163	-123	7080	- 83	7000	- 80	6920	- 80
	13	6815	6935	120	7062	127	7190	128	7313	123
	14	6973	7112	139	7236	124	7365	129	7485	120
	15	6518	6548	30	6575	27	6606	31	6637	31
	16	6324	6505	181	6676	171	6846	169	7011	165
	17	5913	6112	199	6303	191	6496	193	6687	191
	18	6139	6264	125	6384	120	6505	121	6625	120
	19	5833	5869	36	5900	31	5930	30	5961	31
1.76	20	7099	7218	119	7333	115	7450	117	7563	113
	21	7387	7270	-117	7150	-120	7033	-120	6913	-120
	22	6630	6725	100	6817	92	6909	92	7000	91
	23	5665	5563	-102	5460	-103	5360	-100	5261	- 99
	24	7160	7248	88	7330	82	7411	81	7495	84
	25	6300	6210	- 90	6124	- 86	6037	- 87	5950	- 87
	26	6448	6530	82	6610	80	6685	75	6762	77
	27	6402	6320	- 82	6240	- 80	6155	- 85	6072	- 83
	28	7070	7155	85	7232	77	7306	74	7382	76
	29	6700	6617	- 83	6533	84	6450	- 83	6367	- 83

Table VI. Original Data

Stiffening Ring Breadth = 2½" $\tau/\delta = .5$ Load Decreasing   March 23, 1950

Load		33000		22000		11000		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	From Original Reading
1.80	1	5210	-105	5110	-100	5003	-107	4892	00
	2	5550	-133	5411	-139	5274	-137	5127	02
	3	4470	30	4516	46	4552	36	4549	09
	4	5180	52	5219	39	5264	45	5359	09
	5	4927	- 86	4840	- 87	4750	- 90	4654	03
	6	4766	-106	4659	-107	4545	-114	4430	04
	7	5606	- 26	5595	- 11	5578	- 17	5510	04
	8	5303	- 3	5293	- 10	5291	- 2	5338	08
	9	5800	-100	5695	-105	5590	-105	5480	01
	10	5365	-105	5263	-102	5159	-104	5042	02
1.82	11	6229	102	6321	108	6420	101	6485	00
	12	7000	80	7080	80	7165	85	7293	07
	13	7179	-134	7052	-127	6928	-124	6804	11
	14	7356	-129	7226	-130	7105	-121	6970	- 03
	15	6604	- 33	6571	- 33	6550	- 21	6525	07
	16	6840	-171	6666	-174	6500	-166	6320	- 04
	17	6496	-191	6303	-191	6115	-188	5912	- 01
	18	6508	-117	6389	-119	6270	-119	6140	01
	19	5933	- 28	5902	- 31	5876	- 26	5838	05
1.76	20	7452	-111	7342	-110	7229	-113	7100	01
	21	7030	117	7150	120	7270	120	7392	05
	22	6913	- 87	6827	- 85	6736	- 91	6630	00
	23	5364	103	5470	106	5575	105	5684	19
	24	7420	- 75	7340	- 80	7260	- 80	7160	00
	25								
	26	6692	- 68	6620	- 72	6541	- 79	6450	02
	27	6154	82	6238	84	6320	82	6408	06
	28	7313	- 69	7243	- 70	7168	- 75	7073	03
	29	6450	83	6532	82	6619	87	6705	05

Table VI. Original Data

Stiffening Ring Breadth = $2\frac{1}{2}$"		Pure Bending			Load Increasing				March 23, 1950	
Load		0	11000		22000		33000		44000	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.80	1	4882	4968	86	5058	90	5150	92	5235	85
↓	2	5122	5220	98	5310	90	5403	93	5495	92
	3	4530	4548	18	4564	16	4587	23	4617	30
	4	5345	5324	- 21	5310	- 14	5292	- 18	5260	- 32
	5	4646	4731	85	4818	87	4907	89	4990	83
	6	4423	4504	81	4583	79	4663	80	4740	77
	7	5497	5510	13	5518	08	5532	14	5555	23
	8	5324	5295	- 29	5274	- 21	5250	- 24	5210	- 40
	9	5473	5550	77	5628	78	5708	80	5780	72
	10	5035	5105	70	5177	72	5250	73	5322	72
1.82	11	6475	6497	22	6506	9	6518	12	6537	19
↓	12	7287	7243	- 44	7215	- 28	7180	- 35	7133	- 47
	13	6793	6775	- 18	6770	- 05	6760	- 10	6743	- 17
	14	6965	6985	20	7000	15	7010	10	7025	15
	15	6520	6522	02	6525	03	6527	02	6524	- 03
	16	6310	6314	04	6315	01	6317	02	6318	01
	17	5902	5935	33	5968	33	6000	32	6030	30
	18	6130	6203	73	6280	77	6353	73	6426	73
	19	5833	5909	76	5985	76	6060	75	6134	74
1.76	20	7103	7338	235	7570	232	7801	231	8029	228
↓	21	7232	6995	-237	6767	-228	6533	-234	6302	-231
	22	6478	6712	234	6945	233	7173	228	7401	228
	23	5495	5255	-240	5030	-225	4798	-232	4566	-242
	24	6993	7238	245	7483	245	7726	243	7965	239
	25									
	26	6303	6549	246	6790	241	7026	236	7263	237
	27	6240	6000	-240	5763	-239	5523	-240	5285	-238
	28	6929	7170	241	7410	240	7645	235	7881	236
	29	6540	6294	-246	6055	-239	5811	-244	5570	-241

Table VI. Original Data

Stiffening Ring Breadth = $2\frac{1}{2}$"   Pure Bending   Load Decreasing   March 23, 1950

Load		33000		22000		11000		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5160	- 75	5073	- 87	4974	- 99	4882	00
↓	2	5417	- 78	5325	- 92	5228	- 97	5123	01
	3	4590	- 27	4570	- 20	4550	- 20	4534	04
	4	5292	32	5313	21	5329	16	5350	05
	5	4920	- 70	4835	- 85	4740	- 95	4649	03
	6	4674	- 66	4599	- 75	4510	- 89	4426	03
	7	5531	- 24	5519	- 12	5510	- 9	5500	03
	8	5248	38	5277	29	5299	22	5330	06
	9	5720	- 60	5646	- 74	5560	- 86	5474	01
	10	5262	- 60	5192	- 70	5114	- 78	5040	05
1.82	11	6514	- 23	6500	- 14	6500	0	6484	09
↓	12	7170	37	7211	41	7243	32	7290	03
	13	6761	18	6775	14	6780	5	6799	06
	14	7013	- 12	7000	- 13	6990	- 10	6972	07
	15	6522	- 2	6522	0	6525	3	6528	08
	16	6319	1	6319	0	6318	1	6319	09
	17	6008	- 22	5979	- 29	5943	- 36	5909	07
	18	6370	- 56	6399	- 29	6214	- 17	6133	03
	19	6075	- 59	6002	- 73	5920	- 82	5837	04
1.76	20	7820	-209	7591	-229	7349	-242	7100	- 03
↓	21	6528	226	6760	232	7000	240	7243	09
	22	7193	-208	6967	-226	6722	-245	6474	- 04
	23	4796	230	5040	244	5289	249	5541	46
	24	7750	-215	7510	-240	7252	-248	6991	- 03
	25								
	26	7050	-213	6815	-235	6560	-255	6302	- 01
	27	5519	234	5760	241	6003	243	6252	12
	28	7670	-211	7432	-248	7184	-248	6928	- 01
	29	5803	233	6050	247	6299	249	6550	10

Table VI. Original Data

Stiffening Ring Breadth = 2-1/8"		$\tau/\sigma = 0.2$				Load Increasing		March 28, 1950		
Load		0	9100		18000		27000		37740	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.80	1	4865	4970	105	5082	112	5190	108	5320	130
	2	5122	5250	128	5373	123	5500	127	5650	150
	3	4536	4543	07	4530	- 13	4520	- 10	4500	- 20
	4	5353	5295	- 58	5270	- 25	5242	- 28	5210	- 32
	5	4660	4754	94	4851	97	4950	99	5065	115
	6	4458	4560	102	4664	104	4770	106	4893	123
	7	5521	5560	39	5573	13	5585	12	5600	15
	8	5382	5350	- 32	5348	- 02	5345	- 03	5340	- 05
	9	5502	5603	101	5708	105	5810	102	5932	122
	10	5090	5190	100	5286	96	5385	99	5500	115
1.82	11	6536	6503	- 33	6446	- 57	6388	- 58	6320	- 68
	12	7340	7252	- 88	7200	- 52	7139	- 61	7070	- 69
	13	6887	6958	71	7032	74	7106	74	7195	89
	14	7060	7140	80	7218	78	7295	77	7390	95
	15	6840	6850	10	6870	20	6882	12	6900	18
	16	6390	6497	107	6598	101	6697	99	6817	120
	17	5925	6060	135	6189	129	6318	129	6470	152
	18	6185	6300	115	6410	110	6520	110	6650	130
	19	5902	5960	58	6020	60	6080	60	6150	70
1.76	20	7110	7291	181	7470	179	7648	178	7855	207
	21	7333	7159	-174	6986	-173	6810	-176	6610	-200
	22	6575	6742	167	6904	162	7070	166	7265	195
	23									
	24	7110	7275	165	7440	165	7602	162	7800	198
	25	6239	6077	-162	5920	-157	5763	-157	5583	-180
	26	6430	6595	165	6752	157	6913	161	7100	187
	27	6373	6215	-158	6062	-153	5905	-157	5725	-180
	28	7062	7225	163	7382	157	7540	158	7730	190
	29	6673	6512	-161	6357	-155	6200	-157	6012	-188

Table VII. Original Data

Stiffening Ring Breadth = 2-1/8"		$\tau/\sigma = .2$			Load Decreasing			March 28, 1950	
Load		27000		18000		9100		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5200	-120	5082	-118	4973	-109	4863	- 02
	2	5510	-140	5372	-138	5249	-123	5120	- 02
	3	4515	15	4525	10	4545	20	4540	- 04
	4	5248	38	5270	22	5300	30	5358	05
	5	4960	-105	4854	-106	4756	- 98	4658	- 02
	6	4778	-115	4664	-114	4560	-104	4455	- 03
	7	5580	- 20	5562	- 18	5558	- 04	5523	02
	8	5348	08	5343	- 05	5350	07	5382	00
	9	5822	-110	5710	-112	5608	-102	5505	03
	10	5394	-106	5289	-105	5190	- 99	5089	- 01
1.82	11	6380	60	6435	55	6500	65	6543	07
	12	7140	70	7191	51	7253	62	7344	04
	13	7105	- 90	7028	- 77	6953	- 75	6884	- 03
	14	7294	- 96	7210	- 84	7134	- 76	7054	- 06
	15	6875	- 25	6855	- 20	6845	- 10	6833	- 07
	16	6693	-124	6590	-103	6492	- 98	6390	00
	17	6322	-148	6185	-137	6060	-125	5925	00
	18	6535	-115	6415	-120	6305	-110	6191	06
	19	6095	- 55	6029	- 66	5968	- 61	5910	08
1.76	20	7662	-193	7475	-187	7293	-182	7108	- 02
	21	6813	203	6984	171	7163	179	7348	15
	22	7090	-175	6913	-177	6747	-166	6573	- 02
	23								
	24	7623	-177	7450	-173	7280	-170	7110	00
	25	5766	183	5920	154	6082	162	6250	11
	26	6932	-168	6760	-172	6600	-160	6430	00
	27	5905	180	6058	153	6220	162	6383	10
	28	7560	-170	7390	-170	7230	-160	7061	01
	29	6200	188	6350	150	6514	164	6682	09

Table VII. Original Data

Stiffening Ring Breadth = 2-1/8" τ/δ = .35 Load Increasing March 29, 1950

Load		0	10000		20000		30000		40000	
Gage Factor	Gage No.	Indicator Reading	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80	1	4866	4970	104	5078	108	5181	103	5286	105
	2	5124	5260	136	5392	132	5525	133	5655	130
	3	4540	4560	20	4537	- 23	4512	- 25	4489	- 23
	4	5352	5267	- 85	5227	- 40	5189	- 38	5148	- 41
	5	4660	4750	90	4843	93	4937	94	5027	90
	6	4460	4570	110	4677	107	4784	107	4890	106
	7	5530	5600	70	5620	20	5637	17	5655	18
	8	5377	5330	- 47	5328	- 02	5325	- 03	5321	- 04
	9	5510	5608	98	5712	104	5816	104	5920	104
	10	5090	5200	110	5300	100	5402	102	5503	101
1.82	11	6548	6513	- 35	6430	- 83	6355	- 75	6279	- 76
	12	7340	7217	-123	7144	- 73	7067	- 77	6992	- 75
	13	6887	6985	98	7090	105	7194	104	7300	106
	14	7090	7172	82	7280	108	7385	105	7490	105
	15	6830	6850	20	6871	21	6893	22	6915	22
	16	6398	6547	149	6687	140	6827	140	6966	139
	17	5930	6100	170	6264	164	6429	165	6591	162
	18	6196	6311	115	6428	117	6541	113	6656	115
	19	5910	5950	40	5990	40	6032	42	6073	41
1.76	20	7114	7253	139	7394	141	7532	138	7670	138
	21	7343	7205	-138	7065	-140	6925	-140	6785	-140
	22	6578	6700	122	6820	120	6939	119	7058	119
	23	5570	5440	-130	5312	-128	5185	-127	5060	-125
	24	7112	7228	116	7342	114	7457	115	7570	113
	25	6248	6130	-118	6016	-114	5900	-116	5788	-112
	26	6432	6545	113	6655	110	6764	109	6872	108
	27	6384	6274	-110	6160	-114	6050	-110	5940	-110
	28	7064	7178	114	7286	108	7393	107	7500	107
	29	6683	6570	-113	6458	-112	6346	-112	6233	-113

Table VII. Original Data

Stiffening Ring Breadth = 2-1/8"			''/6 = .35			Load Decreasing			March 29, 1950
Load		30000		20000		10000		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5189	- 97	5089	-100	4980	-109	4864	- 02
↓	2	5527	-128	5404	-123	5267	-137	5122	- 02
	3	4512	23	4540	28	4568	28	4544	04
	4	5189	41	5234	45	5274	40	5356	04
	5	4942	- 85	4857	- 85	4760	- 97	4660	00
	6	4788	-102	4688	-100	4577	-111	4457	- 03
	7	5636	- 19	5619	- 17	5600	- 19	5530	00
	8	5326	05	5330	04	5333	03	5378	01
	9	5822	- 98	5727	- 95	5618	-109	5508	- 02
	10	5410	- 93	5313	- 97	5209	-104	5090	00
1.82	11	6350	71	6434	84	6516	82	6547	- 01
↓	12	7070	78	7142	72	7217	75	7338	- 02
	13	7198	-102	7092	-106	6983	-109	6881	- 06
	14	7382	-108	7280	-102	7170	-110	7052	- 38
	15	6890	- 25	6868	- 22	6840	- 28	6820	- 10
	16	6825	-141	6687	-138	6540	-147	6390	- 08
	17	6430	-161	6270	-160	6100	-170	5923	- 07
	18	6550	-106	6442	-108	6316	-126	6190	- 06
	19	6040	- 33	6008	- 32	5953	- 55	5903	- 07
1.76	20	7543	-127	7413	-130	7260	-153	7109	- 05
↓	21	6925	140	7065	140	7203	138	7344	01
	22	6950	-108	6840	-110	6707	-133	6572	- 06
	23	5186	126	5314	128	5440	126	5573	03
	24	7470	-100	7364	-106	7237	-127	7106	- 06
	25	5900	112	6016	116	6130	114	6248	00
	26	6778	- 94	6678	-100	6555	-123	6429	- 03
	27	6050	110	6162	112	6272	-110	6383	- 01
	28	7407	- 93	7308	- 99	7185	-123	7060	- 04
	29	6345	112	6460	115	6570	110	6684	01

Table VII. Original Data

Stiffening Ring Breadth = 2-1/8" τ/σ = .5 Load Increasing March 29, 1950

Load		0	11000		22000		33000		44000	
Gage Factor	Gage No.	Indicator Reading	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.80	1	4852	4963	111	5073	110	5180	107	5288	108
	2	5119	5260	141	5402	142	5542	140	5680	138
	3	4539	4553	14	4520	- 33	4480	- 40	4445	- 35
	4	5350	5246	-104	5202	- 44	5158	- 44	5115	- 43
	5	4657	4743	86	4838	95	4930	92	5022	92
	6	4453	4568	115	4682	114	4793	111	4905	112
	7	5526	5604	78	5624	20	5645	21	5665	20
	8	5372	5312	- 60	5320	08	5320	00	5322	02
	9	5505	5606	101	5717	111	5826	109	5933	107
	10	5086	5200	114	5307	107	5412	105	5520	108
1.82	11	6543	6497	- 46	6400	- 97	6305	- 95	6217	- 88
	12	7336	7193	-143	7110	- 83	7028	- 82	6950	- 78
	13	6885	7005	120	7136	131	7265	129	7400	135
	14	7051	7183	132	7312	129	7440	128	7574	134
	15	6819	6835	16	6862	27	6890	28	6920	30
	16	6392	6573	181	6747	174	6919	172	7097	178
	17	5924	6120	196	6317	197	6510	193	6710	200
	18	6190	6316	126	6440	124	6563	123	6691	128
	19	5902	5932	30	5968	36	6000	32	6040	40
1.76	20	7110	7228	118	7345	117	7461	116	7585	124
	21	7342	7220	-122	7101	-119	6980	-121	6870	-110
	22	6570	6664	94	6760	96	6853	93	6953	100
	23	5570	5466	-104	5365	-101	5261	-104	5167	- 94
	24	7104	7190	86	7275	85	7360	85	7451	91
	25	6245	6151	- 94	6066	- 85	5977	- 89	5898	- 79
	26	6428	6510	82	6590	80	6668	78	6754	86
	27	6382	6300	- 82	6218	- 82	6132	- 86	6058	- 74
	28	7055	7140	85	7220	80	7297	77	7380	83
	29	6683	6600	- 83	6516	- 84	6432	- 84	6355	- 77

Table VII. Original Data

Stiffening Ring Breadth = 2-1/8"		τ/σ = .5				Load Decreasing			March 29, 1950
Load		33000		22000		11000		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5190	- 98	5082	-108	4975	-107	4864	12
↓	2	5546	-134	5410	-136	5270	-140	5120	01
	3	4492	47	4520	28	4559	39	4540	01
	4	5159	44	5210	51	5256	46	5357	07
	5	4938	- 84	4849	- 89	4756	- 93	4660	03
	6	4800	-105	4690	-110	4578	112	4456	03
	7	5652	- 13	5625	- 27	5608	- 17	5527	01
	8	5320	- 02	5322	02	5320	- 02	5374	02
	9	5832	-101	5730	-102	5620	-110	5511	06
	10	5420	-100	5317	-103	5210	-107	5089	03
1.82	11	6305	88	6404	99	6502	98	6552	09
↓	12	7032	82	7114	82	7199	85	7340	04
	13	7271	-129	7138	-133	7010	-128	6887	02
	14	7440	-134	7312	-128	7185	-127	7051	00
	15	6886	- 34	6855	- 31	6827	- 28	6803	- 16
	16	6920	-177	6748	-172	6576	-172	6397	05
	17	6518	-192	6324	-194	6131	-193	5930	06
	18	6573	-118	6453	-120	6330	-123	6200	10
	19	6012	- 28	5981	- 31	5950	- 31	5910	08
1.76	20	7473	-112	7360	-113	7241	-119	7111	01
↓	21	6984	114	7102	118	7222	120	7345	03
	22	6866	- 87	6776	- 90	6680	- 96	6573	03
	23	5266	99	5366	100	5470	104	5580	10
	24	7373	- 78	7293	- 80	7210	- 83	7110	06
	25	5980	82	6067	87	6155	88	6249	04
	26	6682	- 72	6609	- 73	6528	- 81	6432	04
	27	6136	78	6220	84	6303	83	6390	08
	28	7310	- 70	7236	- 74	7158	- 78	7060	05
	29	6435	80	6518	83	6603	85	6691	08

Table VII. Original Data

Stiffening Ring Breadth = 2-1/8"		Pure Bending					Load Increasing		March 29, 1950	
Load		0	11000		22000		33000		44000	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶
1.80	1	4857	4946	89	5037	91	5130	93	5223	93
	2	5111	5210	99	5304	94	5402	98	5508	106
	3	4530	4540	10	4532	- 8	4531	- 1	4532	1
	4	5341	5330	- 11	5335	5	5345	10	5357	12
	5	4650	4739	89	4828	89	4919	91	5011	92
	6	4448	4530	82	4610	80	4692	82	4780	88
	7	5518	5522	4	5506	- 16	5491	- 15	5485	- 6
	8	5355	5336	- 19	5333	- 3	5335	2	5340	5
	9	5501	5580	79	5661	81	5744	83	5832	88
	10	5078	5151	73	5220	69	5291	71	5370	79
1.82	11	6542	6559	17	6550	- 9	6544	- 6	6545	1
	12	7319	7281	- 38	7268	- 13	7259	- 9	7249	- 10
	13	6870	6854	- 16	6844	- 10	6837	- 7	6830	- 7
	14	7044	7060	16	7070	10	7084	14	7104	20
	15	6783	6786	3	6787	1	6790	3	6800	10
	16	6380	6380	0	6376	- 4	6379	3	6381	2
	17	5915	5948	33	5976	28	6010	34	6047	37
	18	6184	6260	76	6332	72	6411	79	6491	80
	19	5895	5970	75	6049	79	6129	80	6212	83
1.76	20	7108	7342	234	7580	238	7812	232	8050	238
	21	7320	7081	-239	6843	-238	6611	-232	6382	-229
	22	6567	6801	234	7038	237	7271	233	7511	240
	23	5553	5309	-244	5062	-247	4824	-238	4590	-234
	24	7103	7351	248	7597	246	7841	244	8091	250
	25	6220	5978	-242	5736	-242	5500	-236	5265	-235
	26	6425	6670	245	6911	241	7154	243	7402	248
	27	6362	6119	-243	5872	-247	5634	-238	5400	-234
	28	7053	7297	244	7538	241	7779	241	8022	243
	29	6665	7415	-250	6169	-246	5928	-241	5690	-238

Table VII. Original Data

Stiffening Ring Breadth = 2-1/8"			Pure Bending			Load Decreasing			March 29, 1950
Load	33000			22000		11000		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5145	- 78	5055	- 90	4958	- 97	4860	03
	2	5420	- 88	5320	-100	5220	-100	5113	02
	3	4530	- 2	4536	- 6	4541	- 5	4531	01
	4	5350	- 7	5340	- 10	5336	- 4	5347	06
	5	4983	- 28	4849	-134	4751	- 98	4658	08
	6	4706	- 74	4623	- 83	4540	- 83	4450	02
	7	5490	5	5504	14	5525	21	5522	04
	8	5340	0	5338	- 2	5340	2	5360	05
	9	5761	- 71	5680	- 81	5592	- 88	5505	04
	10	5307	- 63	5237	- 70	5160	- 77	5081	03
1.82	11	6538	- 7	6540	2	6555	15	6545	03
	12	7258	9	7268	10	7282	14	7321	02
	13	6842	12	6854	12	6862	8	6878	08
	14	7090	- 14	7074	- 16	7066	- 8	7051	07
	15	6789	- 11	6782	- 7	6788	6	6789	06
	16	6380	- 1	6380	0	6387	7	6387	07
	17	6020	- 27	5990	- 30	5958	- 32	5922	07
	18	6430	- 61	6354	- 76	6272	- 82	6190	06
	19	6148	- 64	6069	- 79	5983	- 86	5900	05
1.76	20	7836	-214	7601	-235	7356	-245	7106	- 02
	21	6607	225	6840	233	7082	242	7330	10
	22	7298	-213	7061	-237	6818	-243	6564	- 03
	23	4820	230	5060	240	5310	250	5561	08
	24	7869	-222	7625	-244	7367	-258	7105	02
	25	5495	230	5732	237	5980	248	6230	10
	26	7180	-222	6940	-240	6688	-252	6427	02
	27	5630	230	5870	240	6120	250	6371	09
	28	7801	-221	7563	-238	7311	-252	7052	- 01
	29	5922	232	6161	239	6418	257	6672	07

Table VII. Original Data

Stiffening Ring Breadth = $1\frac{1}{2}$"			$\gamma/ = 0.2$			Load Increasing			April 1,1950	
Load		0	9065		17955		26920		37987	
Gage Factor	Gage No.	Indicator Reading	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80	1	4727	4847	120	4955	108	5066	111	5201	136
	2	4977	5100	123	5230	130	5358	128	5515	157
	3	4378	4387	09	4369	- 18	4350	- 19	4330	- 20
	4	5211	5159	- 52	5129	- 30	5100	- 29	5060	- 40
	5	4525	4633	108	4737	104	4840	103	4968	128
	6	4351	4459	108	4565	106	4672	107	4802	130
	7	5403	5442	39	5450	08	5460	10	5473	13
	8	5235	5210	- 25	5202	- 8	5199	- 03	5190	- 9
	9	5385	5490	105	5592	102	5699	107	5826	127
	10	4956	5062	106	5160	98	5260	100	5383	123
1.82	11	6466	6432	- 34	6380	- 52	6320	- 60	6258	- 62
	12	7214	7134	- 80	7076	- 58	7016	- 60	6940	- 76
	13	6770	6852	82	6923	71	6998	75	7084	86
	14	6948	7023	75	7101	78	7182	81	7281	99
	15	7252	7269	17	7279	10	7290	11	7305	15
	16	6293	6404	111	6508	104	6610	102	6738	128
	17	5839	5977	138	6110	133	6243	133	6410	167
	18	6109	6230	121	6350	120	6470	120	6615	145
	19	5807	5870	63	5931	61	5993	62	6071	78
1.76	20	7000	7183	183	7360	177	7540	180	7760	220
	21	7391	7212	-179	7037	-175	6858	-179	6640	-218
	22	6615	6785	170	6950	165	7116	166	7319	203
	23	5610	5435	-175	5266	-169	5095	-171	4884	-211
	24	7152	7323	169	7488	165	7652	164	7853	201
	25	6270	6107	-163	5947	-160	5785	-162	5588	-203
	26	6430	6596	162	6754	158	6915	161	7110	195
	27	6380	6220	-160	6060	-160	5901	-159	5707	-194
	28	7060	7221	161	7380	159	7539	159	7732	193
	29	6696	6531	-165	6371	-160	6210	-161	6012	-198

Table VIII. Original Data

Stiffening Ring Breadth = $1\frac{1}{2}$"		τ/σ = .2			Load Decreasing			April 1, 1950	
Load		27030		18010		9065		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80	1	5084	-117	4975	-109	4860	-115	4740	13
	2	5372	-143	5247	-125	5115	-132	4991	14
	3	4353	23	4379	26	4400	21	4398	20
	4	5105	45	5139	34	5170	31	5229	18
	5	4859	-109	4755	-104	4650	-105	4540	15
	6	4685	-117	4580	-105	4471	-109	4365	14
	7	5460	- 13	5457	- 03	5452	- 05	5420	17
	8	5203	13	5212	9	5220	8	5251	16
	9	5715	-111	5610	-105	5502	-108	5400	15
	10	5275	-108	5179	- 96	5078	-101	4972	16
1.82	11	6318	60	6379	61	6440	61	6480	14
	12	7020	80	7083	63	7144	61	7232	18
	13	7003	- 81	6935	- 68	6863	- 72	6785	15
	14	7189	- 92	7111	- 78	7032	- 79	6960	12
	15	7290	- 15	7280	- 10	7270	- 10	7260	08
	16	6614	-124	6513	-101	6412	-101	6309	16
	17	6259	-151	6120	-139	5988	-132	5850	11
	18	6490	-125	6370	-120	6245	-125	6120	11
	19	6015	- 56	5950	- 65	5883	- 67	5817	10
1.76	20	7562	-198	7382	-180	7199	-183	7010	10
	21	6854	214	7040	186	7220	180	7405	14
	22	7140	-179	6971	-169	6801	-170	6627	12
	23	5092	208	5270	178	5444	174	5623	13
	24	7678	-175	7510	-168	7339	-171	7162	10
	25	5783	195	5950	167	6113	163	6285	15
	26	6940	-170	6779	-161	6611	-168	6440	10
	27	5900	193	6066	166	6229	163	6395	15
	28	7562	-170	7400	-162	7237	-163	7068	08
	29	6208	196	6375	167	6540	165	6710	14

Table VIII. Original Data

Stiffening Ring Breadth = $1\frac{1}{2}$"		τ/σ = .35				Load Increasing			April 1,1950	
Load		0	10005		20010		29980		39945	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.80	1	4740	4850	110	4959	109	5065	106	5170	105
	2	4990	5122	132	5257	135	5490	133	5523	133
	3	4397	4413	16	4384	- 29	4355	29	4329	- 26
	4	5223	5140	- 83	5100	- 40	5059	- 41	5017	- 42
	5	4540	4640	100	4740	100	4840	100	4939	99
	6	4365	4475	110	4586	111	4696	110	4804	108
	7	5421	5487	66	5502	15	5520	18	5535	15
	8	5249	5200	- 49	5200	0	5197	- 03	5190	- 07
	9	5400	5500	100	5608	108	5715	107	5822	107
	10	4971	5081	110	5188	107	5290	102	5394	104
1.82	11	6480	6446	- 34	6370	- 76	6292	- 78	6218	- 74
	12	7227	7109	-118	7033	- 76	6960	- 73	6885	- 75
	13	6785	6892	107	6999	107	7100	101	7202	102
	14	6960	7068	108	7175	107	7283	108	7390	107
	15	7258	7274	16	7295	21	7314	19	7331	17
	16	6310	6463	153	6610	147	6756	146	6900	144
	17	5850	6025	175	6200	175	6371	171	6544	173
	18	6120	6245	125	6372	127	6500	128	6628	128
	19	5815	5860	45	5906	46	5951	45	6000	49
1.76	20	7008	7150	142	7290	140	7430	140	7570	140
	21	7405	7265	-140	7122	-143	6980	-142	6839	-141
	22	6623	6747	124	6879	132	6989	110	7110	121
	23	5625	5492	-133	5363	-129	5233	-130	5108	-125
	24	7160	7278	118	7392	114	7509	117	7621	112
	25	6285	6166	-119	6050	-116	5935	-115	5820	-115
	26	6439	6550	111	6661	111	6770	109	6880	110
	27	6396	6283	-113	6170	-113	6059	-111	5948	-111
	28	7065	7178	113	7289	111	7397	108	7504	107
	29	6710	6597	-113	6481	-116	6368	-113	6253	-115

Table VIII. Original Data

Stiffening Ring Breadth = $1\frac{1}{2}$"		τ/c = .35			Load Decreasing			April 1, 1950	
Load		30030		20010		10015		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5072	- 98	4970	-102	4860	-110	4744	04
	2	5396	-127	5267	-129	5130	-137	4994	04
	3	4359	30	4390	31	4418	28	4404	07
	4	5060	43	5102	42	5143	41	5230	07
	5	4849	- 90	4753	- 96	4650	-103	4546	06
	6	4700	-104	4596	-104	4481	-115	4370	05
	7	5520	- 15	5502	- 18	5490	- 12	5429	08
	8	5198	08	5200	02	5204	04	5256	07
	9	5722	-100	5620	-102	5509	-111	5401	01
	10	5298	- 96	5200	- 98	5090	-110	4978	07
1.82	11	6286	68	6364	78	6444	80	6485	05
	12	6964	79	7037	73	7111	74	7236	09
	13	7103	- 99	7000	-103	6897	-103	6789	04
	14	7282	-108	7176	-106	7070	-106	6965	05
	15	7310	- 21	7290	- 20	7273	- 17	7260	02
	16	6755	-145	6610	-145	6465	-145	6312	02
	17	6378	-166	6210	-168	6033	-177	5854	04
	18	6510	-118	6390	-120	6259	-131	6120	00
	19	5962	- 38	5923	- 39	5872	- 51	5820	05
1.76	20	7443	-127	7310	-133	7163	-147	7010	02
	21	6980	141	7121	141	7270	149	7411	06
	22	6900	-110	6889	-111	6760	-129	6628	05
	23	5232	124	5362	130	5495	133	5630	05
	24	7520	-101	7414	-106	7291	-123	7165	05
	25	5934	114	6050	116	6170	120	6291	06
	26	6785	- 95	6682	-103	6566	-116	6441	02
	27	6057	109	6170	113	6285	115	6401	05
	28	7410	- 94	7310	-100	7191	-119	7070	05
	29	6367	114	6460	113	6599	119	6718	08

Table VIII. Original Data

Stiffening Ring Breadth = $1\frac{1}{2}$"		τ/σ = .5				Load Increasing			April 1, 1950	
Load		0	11140		22010		32900		43950	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.80	1	4750	4860	110	4967	107	5072	105	5181	109
↓	2	4999	5140	141	5280	140	5420	140	5561	141
	3	4410	4434	24	4400	- 34	4360	- 40	4324	- 36
	4	5233	5120	-113	5070	- 50	5024	- 46	4978	- 46
	5	4550	4649	99	4748	99	4847	99	4947	100
	6	4371	4490	119	4603	113	4718	115	483[illegible]	115
	7	5432	5524	92	5543	19	5562	19	5582	20
	8	5260	5192	- 68	5192	0	5191	- 1	5192	1
	9	5407	5510	103	5620	110	5732	112	5845	113
	10	4980	5100	120	5210	110	5318	108	5429	111
1.82	11	6485	6447	- 38	6355	- 92	6264	- 91	6173	- 91
↓	12	7240	7191	- 49	7008	-183	6922	- 86	6837	- 85
	13	6798	6932	134	7058	126	7182	124	7310	128
	14	6970	7096	126	7226	130	7356	130	7488	132
	15	7264	7286	22	7311	25	7336	25	7362	26
	16	6318	6510	192	6688	178	6865	177	7045	180
	17	5860	6070	210	6270	200	6472	202	6676	204
	18	6126	6264	138	6398	134	6530	132	6666	136
	19	5823	5858	35	5893	35	5930	37	5963	33
1.76	20	7010	7132	122	7250	118	7366	116	7484	118
↓	21	7413	7292	-121	7171	-121	7052	-119	6930	-122
	22	6625	6723	98	6817	94	6910	93	7003	93
	23	5635	5528	-107	5424	-104	5321	-103	5218	-103
	24	7161	7250	89	7332	82	7417	85	7501	84
	25	6294	6203	- 91	6117	- 86	6030	- 87	5941	- 89
	26	6443	6528	85	6606	78	6684	78	6763	79
	27	6406	6322	- 84	6240	- 82	6156	- 84	6070	- 86
	28	7067	7152	85	7229	77	7306	77	7383	77
	29	6720	6633	- 87	6550	- 83	6467	- 83	6382	- 85

Table VIII. Original Data

Stiffening Ring Breadth = $1\frac{1}{2}$" τ/σ = .5 Load Decreasing April 1,1950

Load		33015		22090		11030		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80	1	5080	-101	4975	-105	4867	-108	4750	00
	2	5420	-141	5283	-137	5143	-140	4998	- 01
	3	4370	46	4405	35	4440	35	4411	01
	4	5020	42	5071	51	5122	51	5236	03
	5	4852	- 95	4756	- 96	4656	-100	4550	00
	6	4720	-113	4608	-112	4492	-116	4372	01
	7	5568	- 14	5548	- 20	5525	- 23	5435	03
	8	5188	- 4	5190	2	5193	3	5263	03
	9	5736	-109	5627	-109	5513	-114	5406	- 01
	10	5323	-106	5217	-106	5108	-109	4982	02
1.82	11	6260	- 87	6352	- 92	6446	- 94	6487	02
	12	6924	87	7009	85	7096	87	7244	04
	13	7188	-122	7060	-128	6932	-128	6798	00
	14	7354	-134	7225	-129	7095	-130	6970	00
	15	7333	- 29	7308	- 25	7283	- 25	7264	00
	16	6864	-181	6687	-177	6507	-180	6320	02
	17	6476	-200	6277	-199	6072	-205	5860	00
	18	6538	-128	6408	-130	6273	-135	6126	00
	19	5935	- 28	5903	- 32	5870	- 33	5826	03
1.76	20	7374	-110	7262	-112	7143	-119	7013	03
	21	7050	120	7170	120	7294	124	7417	04
	22	6919	- 84	6830	- 89	6735	- 95	6627	02
	23	5320	102	5423	103	5528	105	5630	01
	24	7426	- 75	7348	- 78	7263	- 85	7163	02
	25	6029	88	6117	88	6205	88	6299	05
	26	6693	- 70	6620	- 73	6540	- 80	6447	04
	27	6152	82	6238	86	6323	85	6408	02
	28	7315	- 68	7243	- 72	7165	- 78	7070	03
	29	6465	83	6550	85	6634	84	6722	02

Table VIII. Original Data

Stiffening Ring Breadth = $1\frac{1}{2}$"		Pure Bending			Load Increasing				April 1,1950	
Load		0	10960		21850		32990		43980	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.80 →	1	4743	4842	99	4938	96	5023	85	5120	97
	2	4999	5092	93	5183	91	5272	89	5370	98
	3	4391	4398	7	4401	3	4408	7	4420	12
	4	5229	5227	- 2	5218	- 9	5202	- 16	5191	- 11
	5	4542	4638	96	4728	90	4815	87	4904	89
	6	4368	4451	83	4530	79	4604	74	4688	84
	7	5417	5413	- 4	5408	- 5	5401	- 7	5409	8
	8	5254	5245	- 9	5230	- 15	5210	- 20	5188	- 22
	9	5403	5484	81	5560	76	5630	70	5705	75
	10	4977	5050	73	5120	70	5188	68	5260	72
1.82 →	11	6478	6480	2	6485	5	5490	5	6504	14
	12	7234	7217	- 17	7195	- 22	7170	- 25	7138	- 32
	13	6784	6778	- 6	6766	- 12	6755	- 11	6740	- 15
	14	6962	6968	4	6974	6	6982	8	6992	10
	15	7250	7253	3	7256	3	7256	0	7254	- 2
	16	6307	6303	- 4	6301	- 3	6296	- 5	6292	- 4
	17	5853	5882	29	5910	28	5928	18	5960	32
	18	6122	6203	81	6282	79	6350	68	6434	84
	19	5823	5910	87	5993	83	6067	74	6155	88
1.76 →	20	7020	7259	239	7493	234	7722	229	7952	235
	21	7393	7152	-241	6915	-237	6680	-235	6442	-238
	22	6625	6862	237	7099	237	7332	233	7568	236
	23	5610	5363	-247	5120	-243	4875	-245	4633	-242
	24	7162	7411	249	7659	248	7901	242	8144	243
	25	6272	6027	-245	5784	-243	5543	-241	5300	-243
	26	6498			6921		7173	252	7417	244
	27	6381	6135	-246	5890	-245	5647	-243	5402	-245
	28	7068	7310	242	7551	241	7792	241	8032	240
	29	6693	6444	-249	6195	-249	5950	-245	5705	-245

Table VIII. Original Data

Stiffening Ring Breadth = $1\frac{1}{2}$"		Pure Bending			Load Decreasing			April 1,1950	
Load		33075		22010		11080		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80	1	5050	- 70	4962	- 88	4860	-102	4753	10
	2	5292	- 78	5205	- 87	5106	- 99	5008	09
	3	4411	- 9	4410	- 1	4407	- 3	4408	17
	4	5213	22	5228	15	5234	6	5243	14
	5	4837	- 67	4753	- 84	4657	- 96	4557	15
	6	4622	- 66	4550	- 72	4464	- 86	4380	12
	7	5405	- 4	5411	6	5420	9	5433	16
	8	5217	29	5238	21	5253	15	5269	15
	9	5650	- 55	5583	- 67	5500	- 83	5417	14
	10	5203	- 57	5140	- 63	5064	- 76	4989	12
1.82	11	6487	- 17	6481	- 6	6485	4	6490	12
	12	7171	33	7200	29	7225	25	7248	14
	13	6765	25	6780	15	6792	12	6800	16
	14	6988	- 4	6983	- 5	6980	- 3	6975	13
	15	7255	1	7256	1	7261	5	7262	12
	16	6300	8	6308	8	6315	7	6320	13
	17	5946	- 14	5923	- 23	5894	- 29	5861	08
	18	6380	- 54	6309	- 71	6220	- 89	6130	08
	19	6094	- 61	6019	- 75	5928	- 91	5832	09
1.76	20	7750	-207	7524	-226	7278	246	7030	10
	21	6673	231	6915	242	7160	245	7410	17
	22	7360	-208	7131	-229	6886	245	6632	07
	23	4872	239	5120	248	5372	252	5628	18
	24	7930	-214	7693	-237	7435	258	7170	08
	25	5540	240	5787	247	6034	247	6289	17
	26	7200	-217	6968	-232	6713	255	6451	
	27	5642	240	5891	249	6142	251	6399	18
	28	7820	-212	7587	-233	7332	255	7075	07
	29	5948	243	6200	252	6451	251	6710	17

Table VIII. Original Data

Stiffening Ring Breadth = 3/4"		τ'/δ = .2				Load Increasing			April 3, 1950	
Load		0	9050		17940		26900		38005	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x106
1.80	1	4941	5062	121	5172	110	5285	113	5426	141
	2	5190	5323	133	5450	127	5580	130	5740	160
	3	4619	4612	- 7	4585	- 27	4560	- 25	4530	- 30
	4	5438	5392	- 46	5355	- 37	5320	- 35	5277	- 43
	5	4750	4879	129	5000	121	5120	120	5270	150
	6	4557	4680	123	4792	112	4908	116	5051	143
	7	5631	5652	21	5650	- 2	5649	- 1	5648	- 1
	8	5469	5448	- 21	5435	- 13	5423	- 12	5409	- 14
	9	5600	5720	120	5830	110	5943	113	6081	138
	10	5191	5306	115	5412	106	5521	109	5657	136
1.82	11									
	12	7310	7239	- 71	7179	- 60	7120	- 59	7045	- 75
	13	6860	6926	66	6984	58	7044	60	7118	74
	14	7013	7094	81	7168	74	7241	73	7336	95
	15	7342	7360	18	7373	13	7385	12	7400	15
	16	6377	6508	131	6628	120	6750	122	6900	150
	17	5894	6064	170	6225	161	6389	164	6590	201
	18	6181	6340	159	6491	151	6643	152	6831	188
	19	5842	5923	81	5999	76	6075	76	6171	96
1.76	20	7073	7258	185	7432	174	7607	175	7823	216
	21	7220	7045	-175	6866	-179	6689	-177	6468	-221
	22	6444	6612	168	6772	160	6932	160	7130	198
	23	5423	5255	-168	5085	-170	4915	-170	4707	-208
	24	6975	7140	165	7300	160	7458	158	7655	197
	25	6094	5936	-158	5776	-160	5618	-158	5422	-196
	26	6259	6420	161	6573	153	6729	156	6920	191
	27	6200	6043	-157	5884	-159	5729	-155	5534	-195
	28	6880	7043	160	7190	150	7345	155	7536	191
	29	6513	6354	-159	6194	-160	6036	-158	5840	-196

Table IX. Original Data

Stiffening Ring Breadth = 3/4"		τ/σ = .2		Load Decreasing				April 3, 1950	
Load		26980		18010		9120		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5301	-125	5183	-118	5064	-119	4940	- 01
	2	5591	-149	5458	-133	5323	-135	5190	00
	3	4558	28	4584	26	4610	26	4621	02
	4	5323	46	5358	35	5391	33	5442	04
	5	5136	-134	5010	-126	4883	-127	4752	02
	6	4919	-132	4800	-119	4680	-120	4559	02
	7	5642	6	5644	- 2	5649	- 5	5634	03
	8	5425	16	5434	9	5448	14	5472	03
	9	5958	-123	5840	-118	5721	-119	5600	00
	10	5532	-125	5420	-112	5310	-110	5194	03
1.82	11								
	12	7118	73	7175	57	7236	61	7315	05
	13	7043	- 75	6981	- 62	6922	- 59	6861	01
	14	7242	- 94	7166	- 76	7091	- 75	7015	02
	15	7380	- 20	7367	- 13	7356	- 11	7345	03
	16	6748	-152	6626	-122	6507	-119	6379	02
	17	6400	-190	6230	-170	6069	-161	5899	05
	18	6666	-165	6509	-157	6356	-153	6191	10
	19	6098	- 73	6012	- 86	5930	- 82	5845	03
1.76	20	7626	-197	7443	-183	7262	-181	7072	- 01
	21	6683	215	6862	179	7044	182	7228	08
	22	6951	-179	6784	-167	6619	-165	6444	00
	23	4911	204	5081	170	5251	170	5430	07
	24	7480	-175	7314	-166	7149	-165	6978	03
	25	5615	193	5773	158	5935	162	6100	06
	26	6750	-170	6589	-161	6428	-161	6259	00
	27	5724	190	5881	157	6040	159	6203	03
	28	7366	-170	7205	-161	7048	-157	6880	00
	29	6032	192	6191	159	6351	160	6520	07

Table IX. Original Data

Stiffening Ring Breadth = 3/4" τ/δ = .35   Load Increasing   April 4, 1950

Load		0	10100		19910		29980		39955	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶
1.80	1	4940	5050	110	5155	105	5266	111	5373	107
	2	5192	5330	138	5462	132	5600	138	5734	134
	3	4622	4620	- 2	4590	- 30	4560	- 30	4530	- 30
	4	5435	5362	- 73	5318	- 44	5273	- 45	5230	- 43
	5	4752	4876	124	4997	121	5120	123	5242	122
	6	4560	4686	126	4807	121	4932	125	5053	121
	7	5640	5676	36	5684	8	5690	6	5698	8
	8	5470	5430	- 40	5422	- 8	5413	- 9	5404	- 9
	9	5603	5726	123	5849	123	5975	126	6098	123
	10	5198	5319	121	5435	116	5553	118	5673	120
1.82	11									
	12	7310	7201	-109	7128	- 73	7053	- 75	6981	- 72
	13	6860	6951	91	7040	89	7130	90	7221	91
	14	7022	7130	108	7233	103	7342	109	7450	108
	15	7345	7365	20	7387	22	7410	23	7432	22
	16	6383	6567	184	6740	173	6919	179	7093	174
	17	5900	6117	217	6327	210	6544	217	6758	214
	18	6234	6401	167	6560	159	6730	170	6892	162
	19	5843	5900	057	5952	052	6012	060	6070	58
1.76	20	7078	7219	141	7352	133	7493	141	7631	138
	21	7220	7081	-139	6943	-138	6802	-141	6663	-139
	22	6440	6560	120	6673	113	6795	122	6911	116
	23	5422	5295	-127	5170	-125	5042	-128	4920	-122
	24	6971	7082	111	7190	108	7301	111	7412	111
	25	6094	5980	-114	5870	-110	5758	-112	5649	-109
	26	6253	6361	108	6463	102	6572	109	6679	107
	27	6200	6090	-110	5981	-109	5872	-109	5767	-105
	28	6877	6984	107	7083	99	7190	107	7297	107
	29	6513	6400	-113	6291	-109	6180	-111	6072	-108

Table IX. Original Data

Stiffening Ring Breadth = 3/4"		$\tau/\sigma = .35$			Load Decreasing			April 4, 1950	
Load		29910		20000		10040		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	5272	-101	5170	-102	5058	-112	4940	00
	2	5601	-133	5473	-128	5333	-140	5191	- 01
	3	4562	32	4593	31	4623	30	4630	08
	4	5275	45	5320	45	5368	48	5440	05
	5	5129	-113	5011	-118	4882	-129	4751	- 01
	6	4933	-120	4816	-117	4690	-126	4560	00
	7	5690	- 8	5682	- 8	5677	- 5	5640	00
	8	5413	9	5423	10	5433	10	5473	03
	9	5980	-118	5861	-119	5731	-130	5602	- 01
	10	5558	-115	5445	-113	5322	-123	5198	00
1.80	11								
	12	7056	75	7130	74	7205	75	7317	07
	13	7130	- 91	7040	- 90	6950	- 90	6861	01
	14	7340	-110	7234	-106	7128	-106	7020	- 02
	15	7405	- 27	7382	- 23	7363	- 19	7348	03
	16	6915	-178	6740	-175	6563	-177	6382	- 01
	17	6545	-213	6335	-210	6117	-218	5897	- 03
	18	6739	-153	6582	-157	6411	-171	6233	- 01
	19	6023	- 47	5973	- 50	5910	- 63	5842	- 01
1.76	20	7501	-130	7371	-130	7226	-145	7075	- 03
	21	6804	141	6945	141	7089	144	7230	10
	22	6804	-107	6695	-109	6571	-124	6440	00
	23	5047	127	5170	123	5300	130	5430	08
	24	7312	-100	7211	-101	7094	-117	6970	- 01
	25	5760	111	5870	110	5985	115	6101	07
	26	6583	- 96	6488	- 95	6373	-115	6255	02
	27	5873	106	5982	109	6095	113	6205	05
	28	7201	- 96	7107	- 94	6994	-113	6875	- 02
	29	6182	110	6292	110	6405	113	6519	06

Table IX. Original Data

Stiffening Ring Breadth = 3/4"		τ/δ = .5				Load Increasing			April 4, 1950	
Load		0	10910		21990		32900		39995	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.80	1	4940	5049	109	5151	102	5254	103	5321	67
↓	2	5190	5336	146	5479	143	5618	139	5705	87
	3	4630	4638	8	4600	- 38	4560	- 40	4533	- 27
	4	5440	5342	- 98	5290	- 52	5240	- 50	5209	- 31
	5	4752	4880	128	5005	125	5127	122	5205	78
	6	4559	4691	132	4823	132	4950	127	5033	83
	7	5640	5703	63	5715	12	5722	7	5728	6
	8	5473	5420	- 53	5413	- 7	5409	- 4	5403	- 6
	9	5604	5736	132	5870	134	6000	130	6085	85
	10	5197	5330	133	5457	127	5581	124	5661	80
1.82	11									
↓	12	7318	7181	-137	7109	- 72	7015	- 94	6962	- 53
	13	6865	6980	115	7100	120	7203	103	7276	73
	14	7020	7151	131	7297	146	7412	115	7495	83
	15	7349	7378	29	7420	42	7439	19	7457	18
	16	6384	6610	226	6840	230	7049	209	7185	136
	17	5900	6152	252	6412	260	6661	249	6822	161
	18	6239	6420	181	6600	180	6770	170	6880	110
	19	5842	5889	47	5928	39	5970	42	6000	30
1.76	20	7073	7194	121	7309	115	7420	111	7493	73
↓	21	7227	7109	-118	6990	-119	6870	-120	6795	- 75
	22	6440	6532	92	6622	90	6711	89	6770	59
	23	5430	5330	-100	5230	-100	5131	- 99	5068	- 63
	24	6971	7051	80	7130	79	7206	76	7258	52
	25	6101	6018	- 83	5936	- 82	5852	- 84	5800	- 52
	26	6253	6331	78	6405	74	5479	74	6522	43
	27	6208	6129	- 79	6050	- 79	5972	- 78	5921	- 51
	28	6874	6954	80	7029	75	7100	71	7142	42
	29	6520	6440	- 80	6360	- 80	6280	- 80	6230	- 50

Table IX. Original Data

Stiffening Ring Breadth = 3/4"		$\tau/\sigma = .5$				Load Decreasing		April 4, 1950	
Load		32920		22080		11060		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	From Original Reading
1.80	1	5259	- 62	5158	-101	5050	-108	4940	00
	2	5614	- 91	5479	-135	5338	-141	5189	- 01
	3	4566	33	4601	35	4640	39	4630	00
	4	5235	26	5290	55	5343	53	5443	03
	5	5130	- 75	5010	-120	4882	-128	4750	- 02
	6	4950	- 83	4821	-129	4691	-130	4558	- 01
	7	5729	1	5717	- 12	5703	- 14	5640	00
	8	5400	- 3	5410	10	5419	9	5477	04
	9	6000	- 85	5872	-128	5739	-133	5601	- 03
	10	5581	- 80	5460	-121	5330	-130	5193	- 04
1.82	11								
	12	7014	52	7098	84	7181	83	7322	04
	13	7202	- 74	7090	-112	6978	-112	6863	- 02
	14	7408	- 87	7277	-131	7148	-129	7019	- 01
	15	7432	- 25	7400	- 32	7372	- 28	7350	01
	16	7040	-145	6827	-213	6608	-219	6381	- 03
	17	6660	-162	6410	-250	6151	-259	5894	- 06
	18	6770	-110	6600	-170	6424	-176	6240	01
	19	5975	- 25	5938	- 37	5895	- 43	5843	01
1.76	20	7424	- 69	7314	-110	7200	-114	7072	- 01
	21	6870	75	6990	120	7110	120	7230	03
	22	6718	- 52	6632	- 86	6541	- 91	6440	00
	23	5131	63	5230	99	5330	100	5434	04
	24	7210	- 48	7140	- 70	7060	- 80	6970	- 01
	25	5852	52	5935	83	6020	85	6103	02
	26	6481	- 41	6415	- 66	6342	- 73	6258	05
	27	5971	50	6050	79	6130	80	6210	02
	28	7101	- 41	7037	- 64	6963	- 74	6875	01
	29	6280	50	6360	80	6441	81	6522	02

Table IX. Original Data

Stiffening Ring Breadth = 3/4"		Pure Bending				Load Increasing			April 4, 1950
Load		0	10940		21900		32920		43980
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶
1.80	1	4940	5048	108	5151	103	5257	106	5360	103
	2	5188	5290	102	5388	98	5487	99	5584	97
	3	4628	4630	2	4625	- 5	4623	- 2	4621	- 2
	4	5438	5420	- 18	5410	- 10	5400	- 10	5383	- 17
	5	4750	4848	98	4947	99	5042	95	5138	96
	6	4558	4645	87	4728	83	4810	82	4895	85
	7	5634	5634	0	5622	- 12	5612	- 10	5604	- 8
	8	5470	5442	- 28	5430	- 12	5410	- 20	5390	- 20
	9	5600	5668	68	5736	68	5802	66	5870	68
	10	5191	5266	75	5337	71	5407	70	5480	73
1.82	11									
	12	7310	7277	- 33	7260	- 17	7238	- 22	7212	- 26
	13	6852	6835	- 17	6822	- 13	6808	- 14	6790	- 18
	14	7013	7018	5	7019	1	7018	- 1	7020	2
	15	7336	7335	- 1	7338	3	7337	- 1	7334	- 3
	16	6370	6360	- 10	6351	- 9	6340	- 11	6329	- 11
	17	5882	5910	28	5936	26	5961	25	5989	28
	18	6247	6344	97	6440	96	6534	94	6630	96
	19	5838	5939	101	6042	103	6142	100	6247	105
1.76	20	7077	7310	233	7542	232	7773	231	8001	228
	21	7226	6990	-236	6754	-236	6520	-234	6287	-233
	22	6460	6697	237	6929	232	7160	231	7390	230
	23	5430	5184	-246	4942	-242	4700	-242	4460	-240
	24	6992	7236	244	7480	244	7722	242	7962	240
	25	6099	5857	-242	5618	-239	5378	-240	5140	-238
	26	6277	6519	242	6760	241	6998	238	7238	240
	27	6202	5959	-243	5717	-242	5473	-244	5232	-241
	28	6898	7134	236	7373	239	7610	237	7848	238
	29	6518	6270	-248	6027	-243	5780	-247	5536	-244

Table IX. Original Data

Stiffening Ring Breadth = 3/4"		Pure Bending		Load Decreasing				April 4, 1950	
Load		32960		20600		11060		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	From Original Reading
1.80	1	5274	- 86	5158	-116	5056	-102	4940	00
	2	5500	- 84	5390	-110	5298	- 92	5187	- 01
	3	4620	- 1	4622	2	4628	6	4628	00
	4	5400	17	5412	12	5420	8	5438	00
	5	5060	- 78	4952	-108	4859	- 93	4750	00
	6	4822	- 73	4729	- 93	4650	- 79	4556	- 02
	7	5608	4	5620	12	5631	11	5637	03
	8	5412	22	5430	18	5443	13	5470	00
	9	5820	- 50	5743	- 77	5678	- 65	5602	02
	10	5419	- 61	5340	- 79	5271	- 69	5190	- 01
1.82	11								
	12	7235	23	7256	21	7274	18	7310	00
	13	6810	20	6827	17	6840	13	6857	05
	14	7018	- 2	7018	0	7017	- 1	7012	- 01
	15	7330	- 4	7330	0	7333	3	7337	01
	16	6340	11	6351	11	6360	9	6370	00
	17	5972	- 17	5943	- 29	5916	- 27	5881	- 01
	18	6561	- 69	6462	- 99	6375	- 87	6315	68
	19	6166	- 81	6052	-114	5952	-100	5835	- 03
1.76	20	7790	-211	7530	-260	7318	-212	7070	- 07
	21	6515	228	6780	265	6990	210	7232	06
	22	7178	-212	6919	-259	6705	-214	6454	- 06
	23	4699	239	4970	271	5186	216	5435	05
	24	7743	-219	7471	-272	7248	-223	6987	- 05
	25	5376	236	5646	270	5858	212	6105	06
	26	7020	-218	6752	-268	6531	-221	6272	- 05
	27	5470	238	5743	273	5960	217	6210	08
	28	7630	-218	7365	-265	7145	-220	6890	- 08
	29	5778	242	6053	275	6270	217	6523	05

Table IX. Original Data

Stiffening Ring Breadth = 7/16" t/b = .2 Load Incr-Decreasing April 5, 1950

Load		0	19040		37980		0	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	4952	5209	257	5456	247	4950	- 02
	2	5166	5439	273	5715	276	5162	- 04
	3	4611	4562	- 49	4503	- 59	4609	- 02
	4	5440	5351	- 89	5272	- 79	5438	- 02
	5	4761	5035	274	5299	264	4758	- 03
	6	4551	4847	296	5143	296	4547	- 04
	7	5622	5628	6	5618	- 10	5622	00
	8							
	9	5618	5881	263	6131	250	5615	- 03
	10	5190	5453	263	5723	270	5188	- 02
1.82	11							
	12	7280	7174	-106	7088	- 86	7280	00
	13	6850	6996	146	7135	139	6849	- 01
	14	7000	7130	130	7258	128	6998	- 02
	15	7357	7381	24	7409	28	7353	- 04
	16	6430	6713	183	6998	185	6427	- 03
	17	5867	6282	315	6698	316	5863	- 04
	18	6152	6523	371	6883	360	6150	- 02
	19	5853	6033	180	6211	178	5851	- 02
1.76	20	7060	7440	380	7812	372	7057	- 03
	21	7162	6785	-377	6408	-377	7167	05
	22	6397	6742	345	7080	338	6397	00
	23	5380	5018	-362	4663	-355	5384	04
	24	6934	7272	338	7607	335	6933	- 01
	25	6060	5723	-337	5392	-331	6064	04
	26	6259	6590	331	6915	325	6260	01
	27	6194	5864	-330	5537	-327	6200	06
	28	6871	7198	327	7521	323	6870	- 01
	29	6497	6160	-337	5828	-332	6500	03

Table X. Original Data

Stiffening Ring Breadth = 7/16" b/t = .35   Load Incr-Decreasing   April 7, 1950

Load		0	20110		36885		0	
Gage Factor	Gage No.	Indicator Reading		Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80	1	4950	5182	232	5370	188	4950	00
	2	5163	5422	259	5645	223	5160	- 03
	3	4610	4560	- 50	4501	- 59	4610	00
	4	5435	5329	106	5252	77	5437	02
	5	4759	5025	266	5240	215	4758	- 01
	6	4549	4851	302	5109	258	4545	- 04
	7	5623	5651	28	5651	0	5623	00
	8							
	9	5618	5890	272	6114	224	5613	- 05
	10	5191	5480	289	5730	250	5288	- 03
1.82	11							
	12	7275	7140	-135	7050	- 90	7277	02
	13	6850	7050	200	7220	170	6849	- 01
	14	7000	7181	181	7332	151	7000	00
	15	7356	7390	34	7430	40	7354	- 02
	16	6431	6830	399	7168	338	6430	- 01
	17	5870	6390	520	6840	450	5869	- 01
	18	6152	6540	390	6860	320	6151	- 01
	19	5852	5980	128	6087	107	5853	01
1.76	20	7056	7339	283	7575	236	7055	- 01
	21	7170	6889	-281	6649	-240	7171	01
	22	6395	6630	235	6831	201	6395	00
	23	5388	5132	-256	4924	-208	5390	02
	24	6932	7150	218	7337	187	6933	01
	25	6068	5846	-222	5660	-186	6070	02
	26	6260	6470	210	6648	178	6260	00
	27	6202	5990	-212	5810	-180	6205	03
	28	6870	7081	211	7258	177	6872	02
	29	6503	6285	-218	6100	-185	6508	05

Table X. Original Data

Stiffening Ring Breadth = 7/16" $\tau/\sigma = .5$ Load Incr-Decreasing April 6, 1950

Load		0	20360		34750		0	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	4949	5163	214	5312	149	4949	00
	2	5161	5410	249	5590	180	5162	01
	3	4594	4543	- 51	4490	- 53	4599	05
	4	5432	5318	-114	5253	- 65	5438	06
	5	4756	5013	257	5192	179	4757	01
	6	4544	4847	303	5065	218	4545	01
	7	5618	5657	39	5660	3	5620	02
	8							
	9	5613	5890	277	6082	192	5612	- 01
	10	5188	5489	301	5709	220	5188	00
1.82	11							
	12	7267	7127	-140	7055	- 72	7271	04
	13	6843	7077	-234	7242	-165	6845	02
	14	6998	7207	209	7352	145	6999	01
	15	7347	7394	47	7438	44	7349	02
	16	6430	6890	460	7223	333	6430	00
	17	5887	6467	580	6885	418	5885	- 02
	18	6166	6560	394	6833	273	6166	00
	19	5858	5956	98	6023	67	5860	02
1.76	20	7050	7274	224	7433	159	7052	02
	21	7163	6947	-216	6788	-159	7168	05
	22	6387	6560	173	6680	120	6390	03
	23	5390	5209	-181	5080	-129	5393	03
	24	6932	7081	149	7185	104	6935	03
	25	6068	5920	-148	5813	-107	6072	04
	26	6251	6391	140	6490	99	6256	05
	27	6202	6068	-134	5968	-100	6210	08
	28	6868	7010	142	7107	97	6870	02
	29	6502	6362	-140	6260	-102	6508	06

Table X. Original Data

Stiffening Ring Breadth = 7/16"	Pure Bending	Load Incr-Decreasing	April 6, 1950					
Load		0	21910		43925		0	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	From Original Reading
1.80	1	4949	5163	214	5377	214	4949	00
	2	5161	5390	229	5614	224	5162	01
	3	4589	4574	- 15	4561	- 13	4592	03
	4	5434	5404	- 30	5370	- 34	5434	00
	5	4756	4952	196	5143	191	4757	01
	6	4542	4745	103	4943	98	4541	- 01
	7	5612	5585	- 27	5560	- 25	5614	02
	8							
	9	5610	5753	143	5895	142	5610	00
	10	5183	5323	140	5460	137	5185	02
1.82	11							
	12	7268	7242	- 26	7207	- 35	7270	02
	13	6838	6810	- 28	6777	- 33	6840	02
	14	6990	6983	- 7	6977	- 6	6993	03
	15	7340	7345	5	7340	- 5	7342	02
	16	6419	6382	- 37	6340	- 42	6422	03
	17	5877	5933	56	5989	56	5876	- 01
	18	6160	6367	207	6572	205	6160	00
	19	5856	6077	221	6298	221	5854	- 02
1.76	20	7053	7527	474	7993	466	7051	- 02
	21	7152	6676	-476	6200	-476	7155	03
	22	6392	6865	473	7332	467	6390	- 02
	23	5380	4888	-492	4399	-489	5382	02
	24	6940	7432	492	7920	488	6940	00
	25	6058	5570	-488	5084	-486	6060	02
	26	6262	6750	488	7232	482	6262	00
	27	6193	5702	-491	5212	-490	6197	04
	28	6875	7358	483	7838	480	6873	- 02
	29	6491	5994	-497	5500	-494	6495	04

Table X. Original Data

Stiffening Ring Breadth - 7/16" $t/\delta = .2$ Load Increasing April 25, 1950

Load		0	9000		18020		27000		37950	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.77	1A	6964	6943	- 21	6900	- 43	6855	- 45	6803	- 52
↓	2A	4997	4927	- 70	4878	- 49	4828	- 50	4766	- 62
	3A	5829	5892	63	5957	65	6020	63	6098	78
	4A	5969	6028	59	6078	50	6125	47	6188	63
	5A	6742	6696	- 46	6632	- 64	6567	- 65	6490	- 77
	6A	5204	5127	- 77	5066	- 61	5008	- 58	4932	- 76
	7A	6595	6567	- 28	6502	- 65	6440	- 62	6365	- 75
	8A	5370	5440	70	5510	70	5580	70	5664	84
	9A	5714	5690	- 24	5633	- 57	5580	- 53	5512	- 68
1.82	15	7505	7516	11	7529	13	7542	13	7557	15
↓	16	6575	6715	140	6851	136	6988	137	7152	164
	17	6101	6298	197	6498	200	6697	199	6938	241
	18	6400	6567	167	6734	167	6900	166	7102	202
	19	6010	6090	80	6173	83	6255	82	6357	102

Load Decreasing

		17940		0	From Original Reading
1.77	1A	6900	97	6970	06
↓	2A	4885	119	5007	10
	3A	5953	-145	5828	- 01
	4A	6072	-116	5970	01
	5A	6631	141	6750	08
	6A	5072	140	5216	12
	7A	6500	135	6602	07
	8A	5510	154	5370	00
	9A	5633	121	5720	06
1.82	15	7519	- 38	7503	- 02
↓	16	6847	-305	6577	02
	17	6507	-431	6098	- 03
	18	6756	-346	6396	- 04
	19	6200	-157	6008	- 02

Table XI. Original Data

Stiffening Ring Breadth = 7/16"			t/s = .35			Load Increasing			April 25, 1950	
Load		0	9150		18050		27030		36015	
Gage Factor	Gage No.	Indicator Reading	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6	Indicator Reading	Strain Increment x10^6
1.77	1A	6970	6943	- 27	6884	- 59	6826	- 58	6767	- 59
↓	2A	5001	4897	-104	4834	- 63	4771	- 63	4708	- 53
	3A	5828	5910	82	5993	83	6078	85	6162	84
	4A	5970	6049	79	6111	62	6175	64	6240	65
	5A	6749	6683	- 66	6595	- 88	6510	- 85	6420	- 90
	6A	5209	5094	-115	5020	- 74	4945	- 75	4869	- 76
	7A	6603	6570	- 33	6491	- 79	6413	- 78	6334	- 79
	8A	5370	5449	79	5530	81	5613	83	5698	85
	9A	5720	5693	- 27	5624	- 69	5556	- 68	5488	- 68
1.82	15	7503	7516	13	7538	22	7560	22	7580	20
↓	16	6580	6762	182	6943	181	7127	184	7310	183
	17	6100	6341	241	6577	236	6813	236	7052	239
	18	6397	6569	172	6730	161	6890	160	7057	167
	19	6008	6066	58	6116	50	6166	50	6223	57

				Load Decreasing	
		18000		0	From Original Reading
1.77	1A	6887	120	6970	00
↓	2A	4840	132	5005	04
	3A	5989	-173	5823	- 05
	4A	6105	-135	5968	- 02
	5A	6600	180	6747	- 02
	6A	5024	155	5217	08
	7A	6490	156	6604	01
	8A	5528	-170	5368	- 02
	9A	5623	135	5725	05
1.82	15	7531	- 49	7504	01
↓	16	6940	-370	6580	00
	17	6584	-468	6100	00
	18	6741	-316	6393	- 04
	19	6132	- 91	6009	01

Table XI. Original Data

Stiffening Ring Breadth = 7/16" r/δ = .5 Load Increasing April 25, 1950

Gage Factor	Gage No.	Load 0: Indicator Reading	9070: Indicator Reading	9070: Strain Increment x10^6	18130: Indicator Reading	18130: Strain Increment x10^6	27040: Indicator Reading	27040: Strain Increment x10^6	34945: Indicator Reading	34945: Strain Increment x10^6
1.77	1A	6970	6940	- 30	6870	- 70	6802	- 68	6745	- 57
↓	2A	5000	4883	-117	4813	- 70	4750	- 63	4690	- 60
	3A	5826	5920	94	6017	97	6110	93	6198	88
	4A	5969	6053	84	6123	70	6198	75	6260	62
	5A	6748	6673	- 75	6572	-101	6464	-108	6383	- 81
	6A	5208	5081	-127	5000	- 81	4916	- 84	4845	- 71
	7A	6601	6565	- 36	6474	- 91	6390	- 84	6312	- 78
	8A	5370	5458	88	5547	89	5638	91	5715	77
	9A	5720	5690	- 30	5610	- 80	5536	- 74	5470	- 66
1.82	15	7502	7519	17	7542	23	7570	28	7593	23
↓	16	6580	6785	205	6995	210	7201	206	7386	185
	17	6100	6360	260	6623	263	6880	257	7108	228
	18	6397	6567	170	6731	164	6892	161	7033	141
	19	6008	6051	43	6090	39	6128	38	6157	29

Load Decreasing

Gage Factor	Gage No.	18060: Indicator Reading	18060: Strain Increment x10^6	0: Indicator Reading	0: From Original Reading
1.77	1A	6879	134	6970	00
↓	2A	4821	131	5008	08
	3A	6010	-188	5820	- 06
	4A	6118	-142	5960	- 09
	5A	6580	197	6750	02
	6A	5003	158	5220	12
	7A	6479	167	6605	04
	8A	5541	-174	5367	- 03
	9A	5613	143	5720	00
1.82	15	7540	- 53	7500	- 02
↓	16	6990	-396	6578	- 02
	17	6621	-487	6100	00
	18	6732	-301	6390	- 07
	19	6093	- 64	6006	- 02

Table XI. Original Data

Stiffening Ring Breadth = 7/16"		Pure Bending			Load Increasing				April 25, 1950	
Load		0	11060		22030		33050		44000	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶	Indicator Reading	Strain Increment x10⁶
1.77	1A	6980	7010	30	7030	20	7055	25	7088	33
	2A	5013	4990	- 23	4975	- 15	4957	- 18	4928	- 29
	3A	5828	5815	- 13	5797	- 18	5782	- 15	5760	- 22
	4A	5976	5975	- 1	5971	- 4	5970	- 1	5971	1
	5A	6761	6799	38	6825	26	6850	25	6895	45
	6A	5222	5202	- 20	5193	- 9	5180	- 13	5155	- 25
	7A	6613	6640	27	6648	8	6662	14	6682	20
	8A	5371	5380	9	5390	10	5398	8	5404	6
	9A	5728	5748	20	5757	9	5768	11	5787	19
1.82	15	7495	7490	- 5	7488	- 2	7483	- 5	7475	- 8
	16	6570	6543	- 27	6518	- 25	6492	- 26	6465	- 27
	17	6090	6112	22	6136	24	6160	24	6182	22
	18	6390	6490	100	6591	101	6691	100	6790	99
	19	6005	6117	112	6230	113	6341	111	6452	111
Load Decreasing										
			21900		0	From Original Reading				
1.77	1A		7030	- 58	6976	- 04				
	2A		4975	47	5013	00				
	3A		5801	41	5830	02				
	4A		5970	- 1	5978	02				
	5A		6814	- 81	6758	- 03				
	6A		5191	36	5223	01				
	7A		6639	- 43	6612	- 01				
	8A		5393	- 11	5371	00				
	9A		5751	- 36	5726	- 02				
1.82	15		7479	4	7495	00				
	16		6515	50	6570	00				
	17		6148	- 34	6087	- 03				
	18		6618	-172	6386	- 04				
	19		6258	-194	6001	- 04				

Table XI. Original Data

Figure XXV

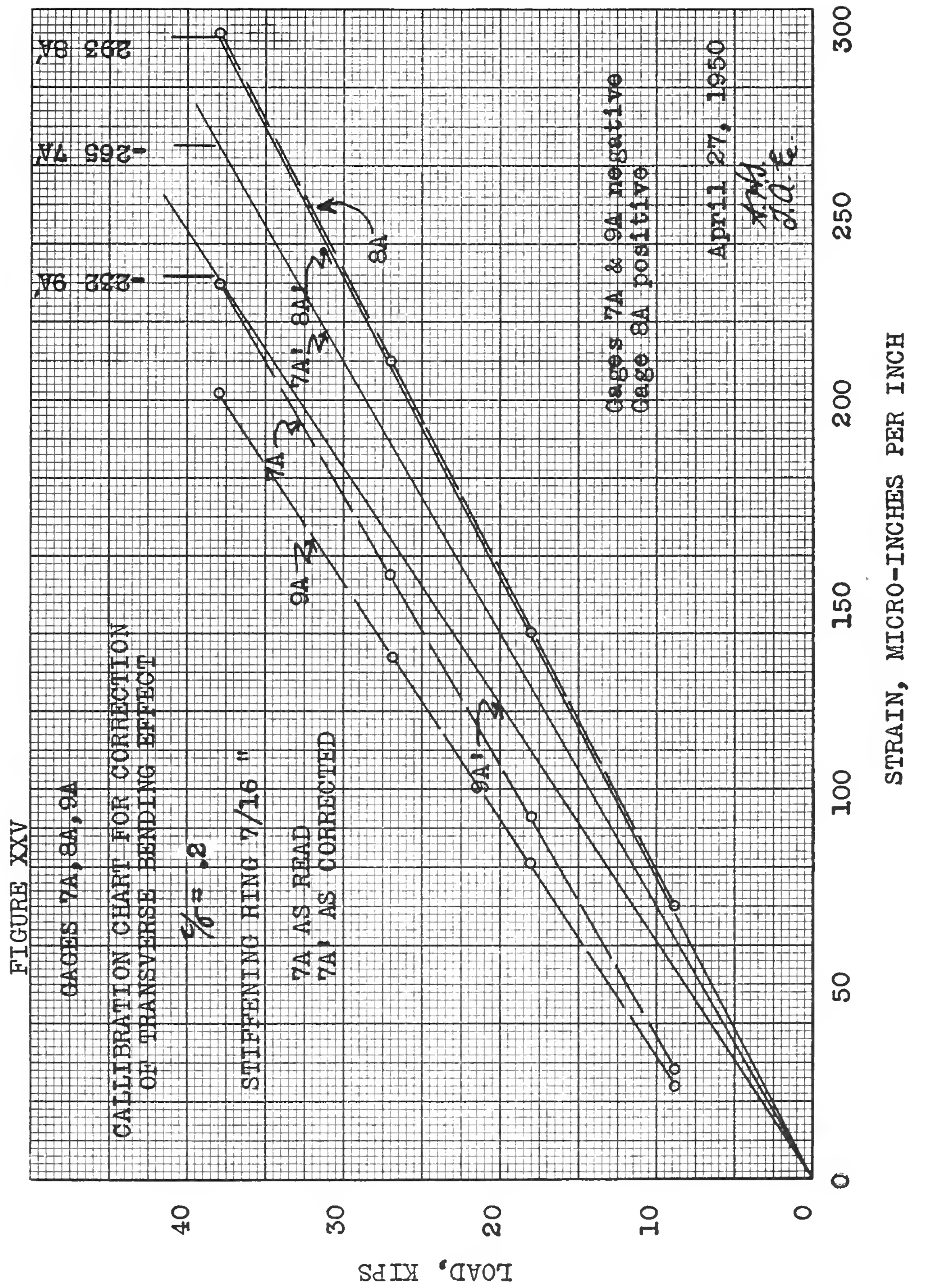


FIGURE XXV
GAGES 7A, 8A, 9A
CALLIBRATION CHART FOR CORRECTION
OF TRANSVERSE BENDING EFFECT
STIFFENING RING 7/16"
7A AS READ
7A' AS CORRECTED
Gages 7A & 9A negative
Gage 8A positive
April 27, 1950
293 8A
265 7A
232 9A
7A
7A' 8A'
8A
9A
9A'
LOAD, KIPS
0
10
20
30
40
STRAIN, MICRO-INCHES PER INCH
0
50
100
150
200
250
300

Figure XXVI

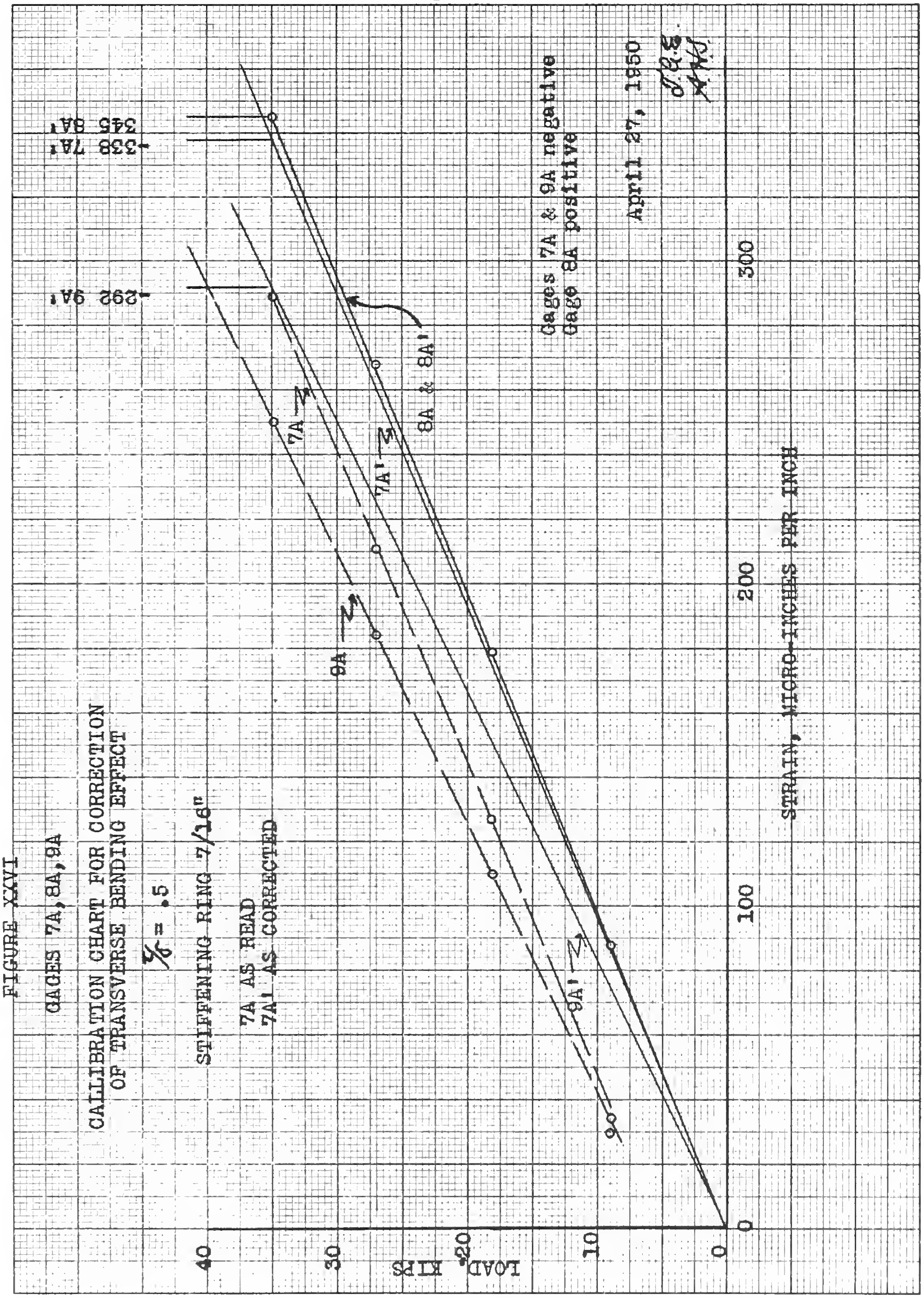


FIGURE XXVI
GAGES 7A, 8A, 9A
CALIBRATION CHART FOR CORRECTION
OF TRANSVERSE BENDING EFFECT
= .5
STIFFENING RING 7/16"
7A AS READ
7A' AS CORRECTED
-338 7A'
345 8A'
-292 9A'
Gages 7A & 9A negative
Gage 8A positive
April 27, 1950
7A
7A'
8A & 8A'
9A
9A'
LOAD, KIPS
0
10
20
30
40
0
100
200
300
STRAIN, MICRO-INCHES PER INCH

Figure XXVII

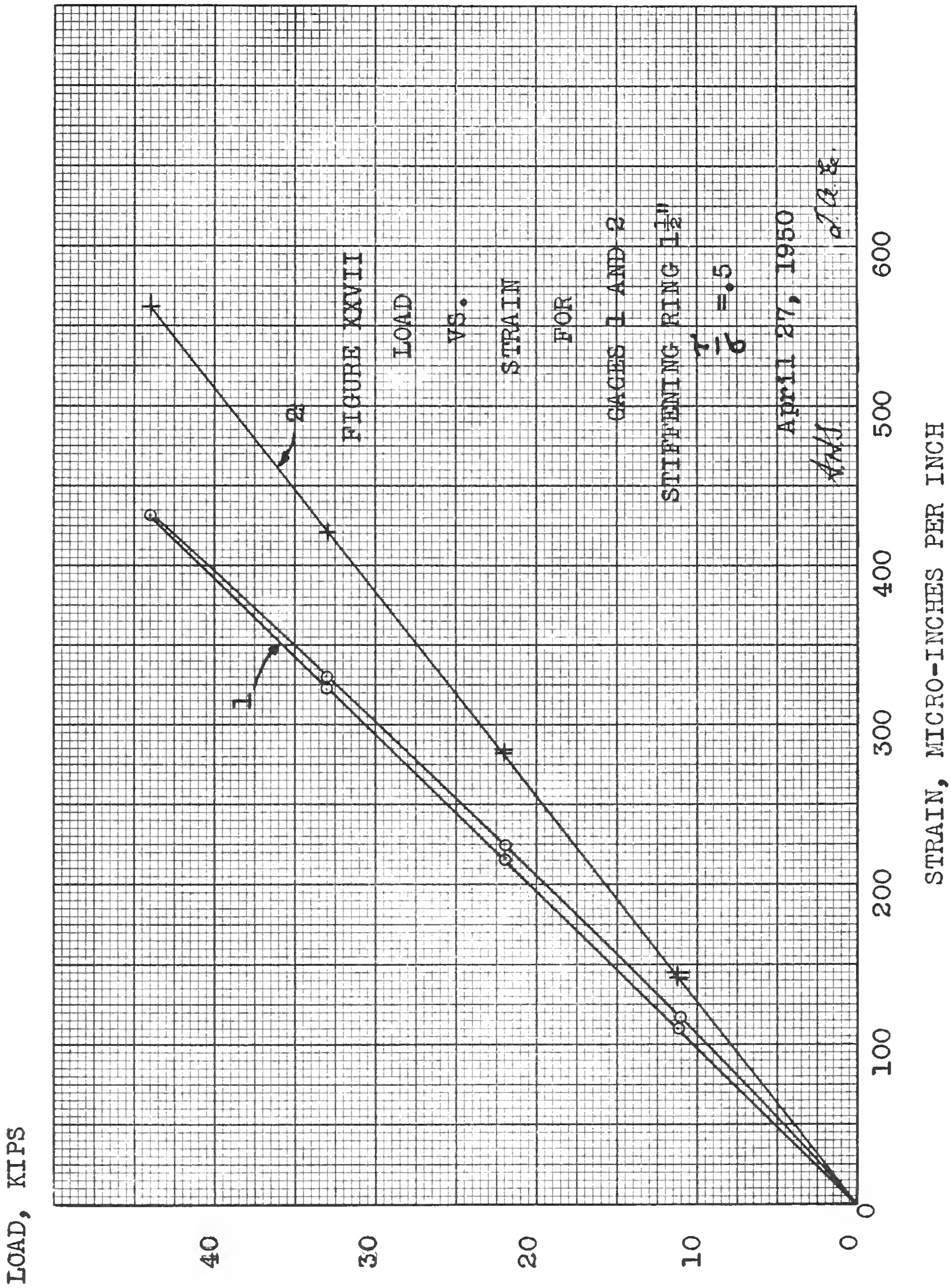


Figure XXVIII

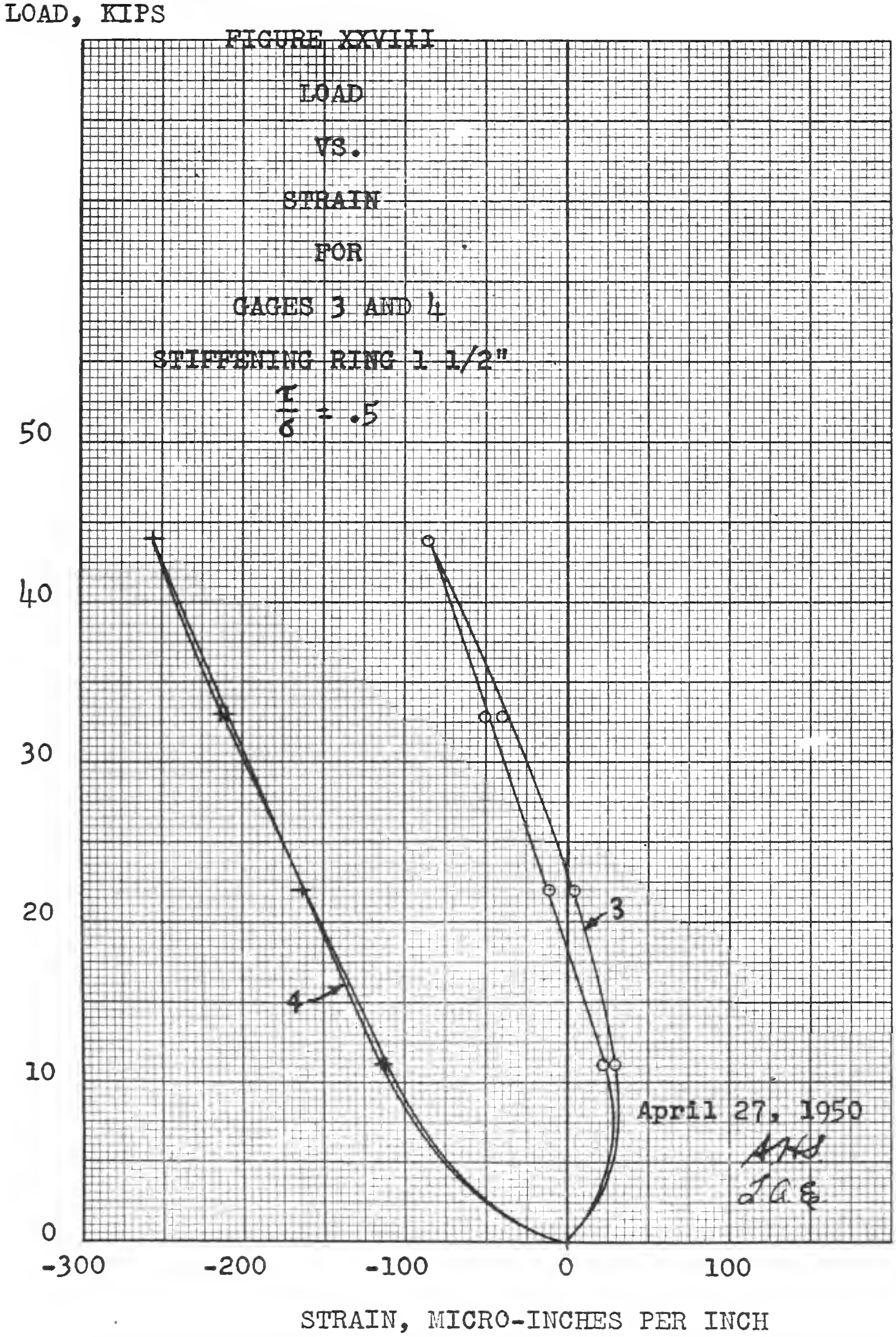


Figure XXIX

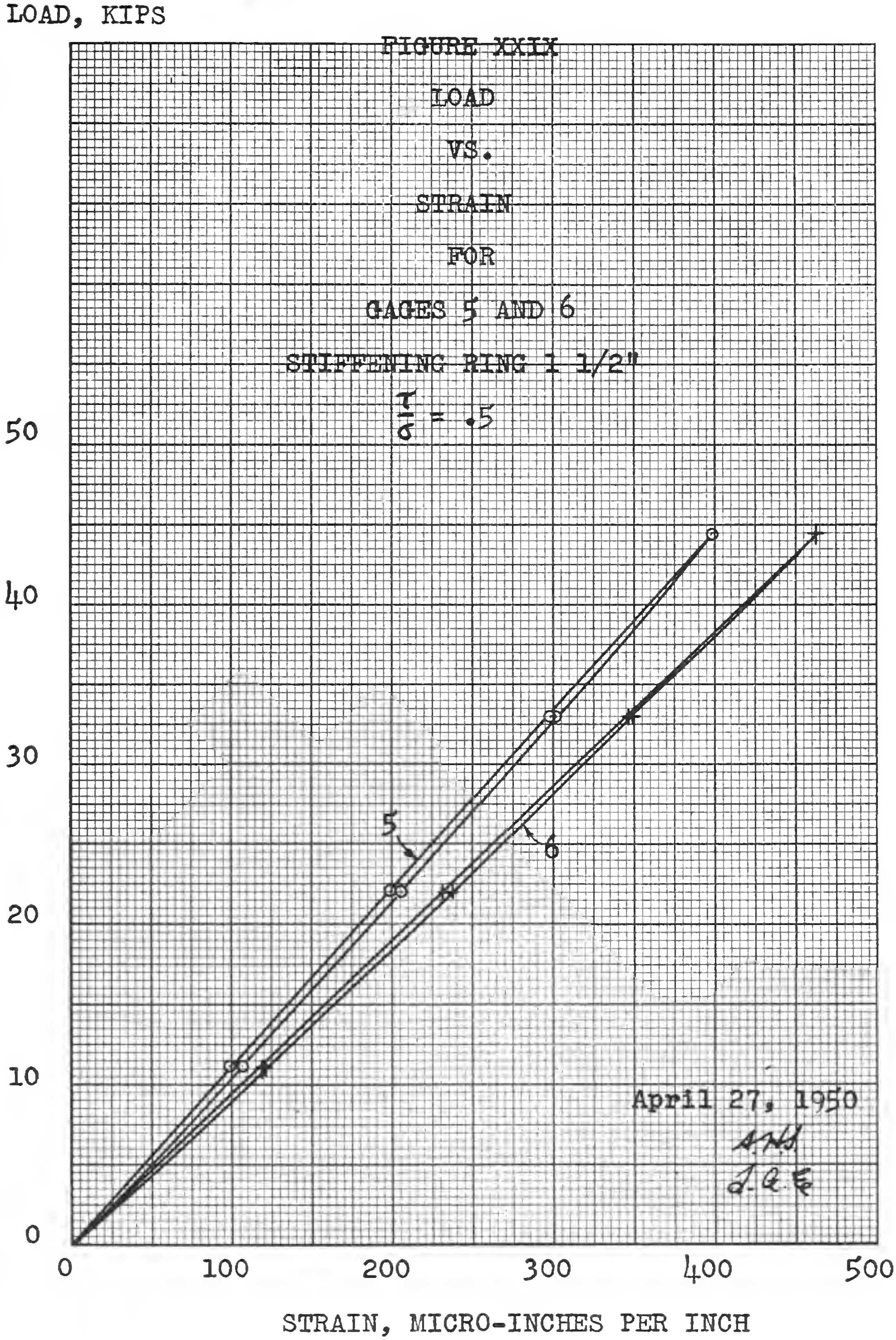

LOAD, KIPS
FIGURE XXIX
LOAD
VS.
STRAIN
FOR
GAGES 5 AND 6
STIFFENING RING 1 1/2"
$\frac{\tau}{\sigma} = .5$
50
40
30
20
10
0
5
6
April 27, 1950
0
100
200
300
400
500
STRAIN, MICRO-INCHES PER INCH

Figure XXX

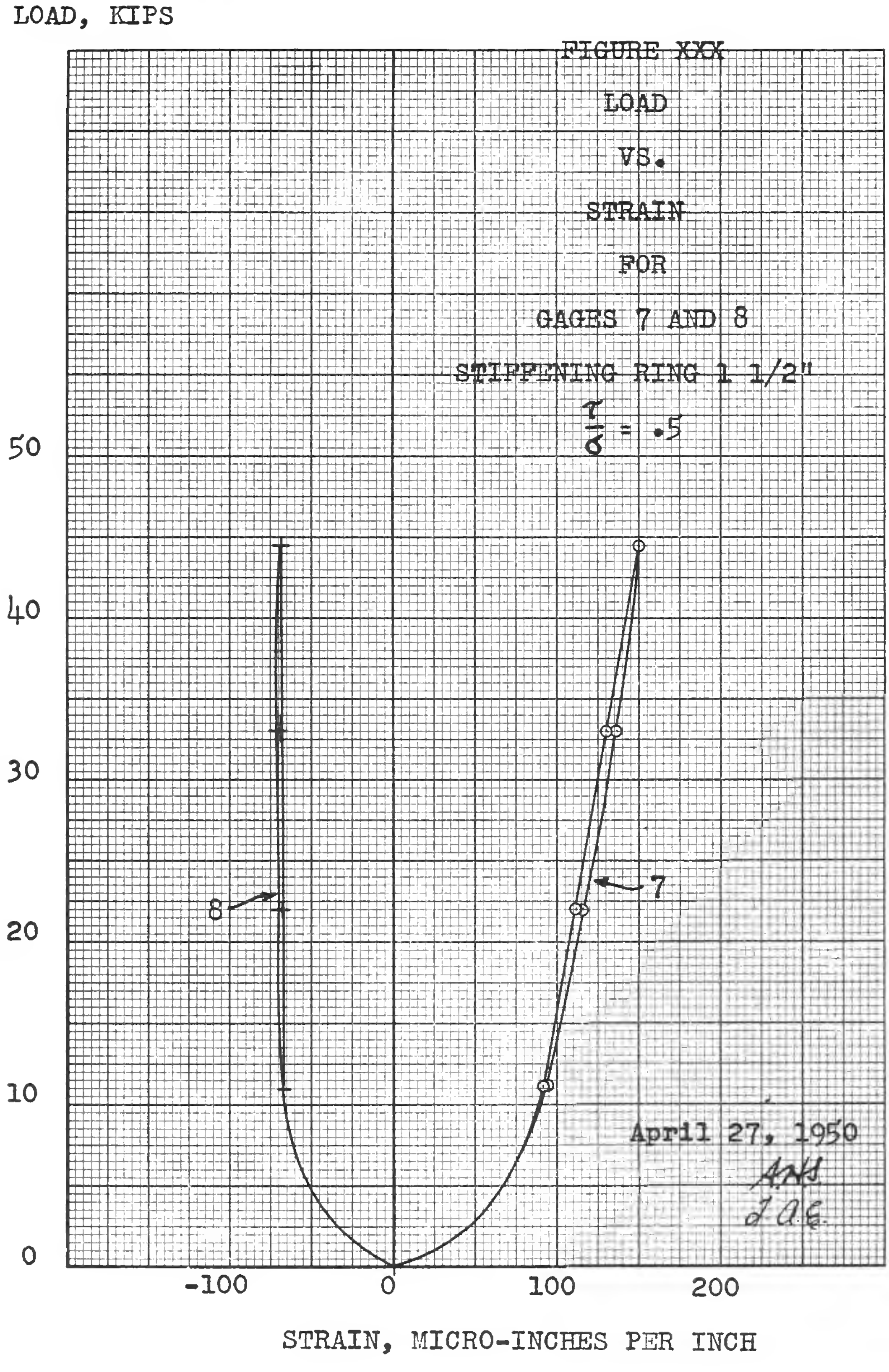

LOAD, KIPS
FIGURE XXX
LOAD
VS.
STRAIN
FOR
GAGES 7 AND 8
STIFFENING RING 1 1/2"
$\frac{\tau}{\sigma} = .5$
50
40
30
20
10
0
8
7
April 27, 1950
A.N.L.
J.A.E.
-100
0
100
200
STRAIN, MICRO-INCHES PER INCH

Figure XXXI

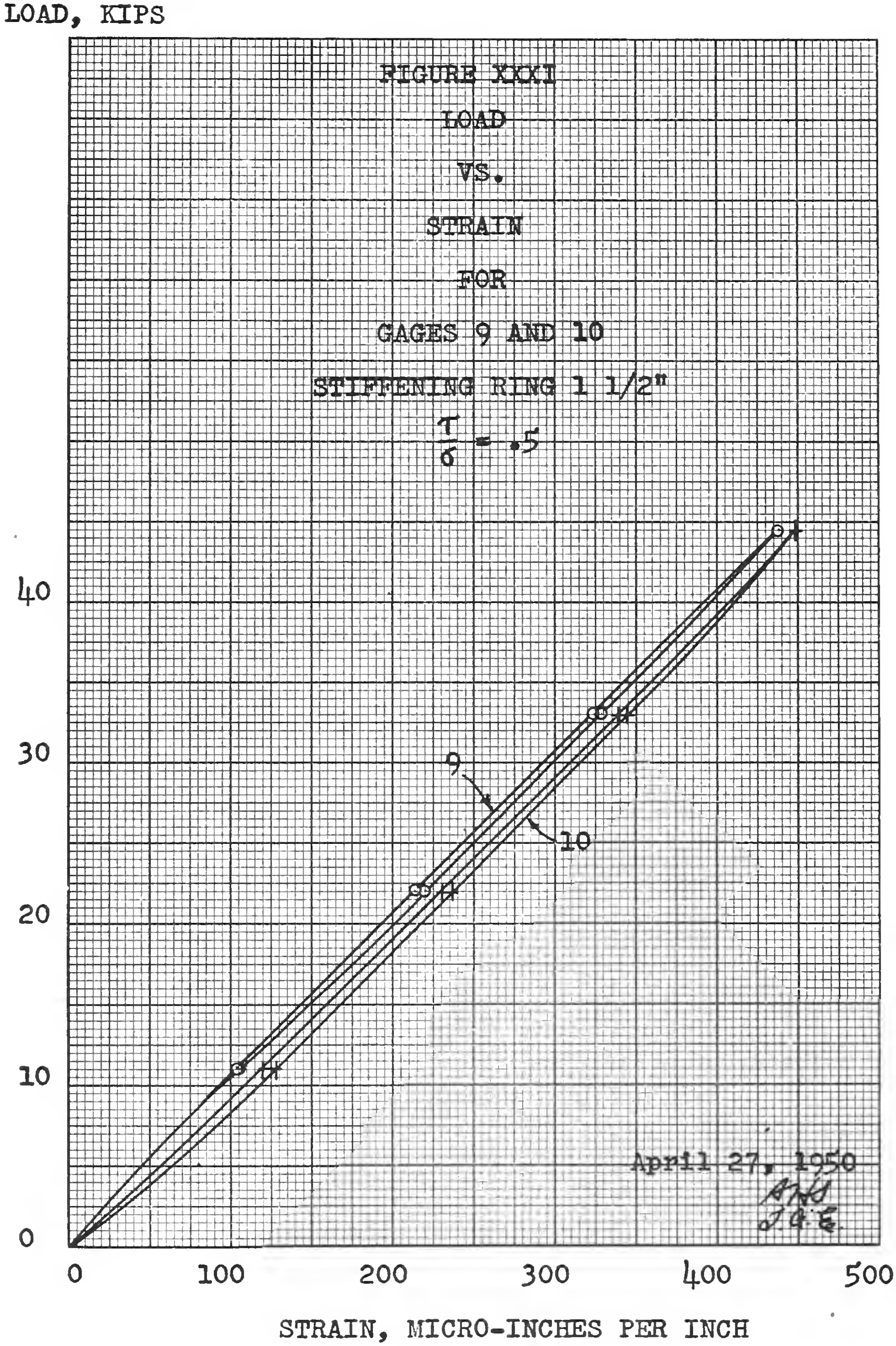

LOAD, KIPS
FIGURE XXXI
LOAD
VS.
STRAIN
FOR
GAGES 9 AND 10
STIFFENING RING 1 1/2"
$\frac{\tau}{\sigma} = .5$
40
30
20
10
0
9
10
0
100
200
300
400
500
April 27, 1950
STRAIN, MICRO-INCHES PER INCH

Figure XXXII

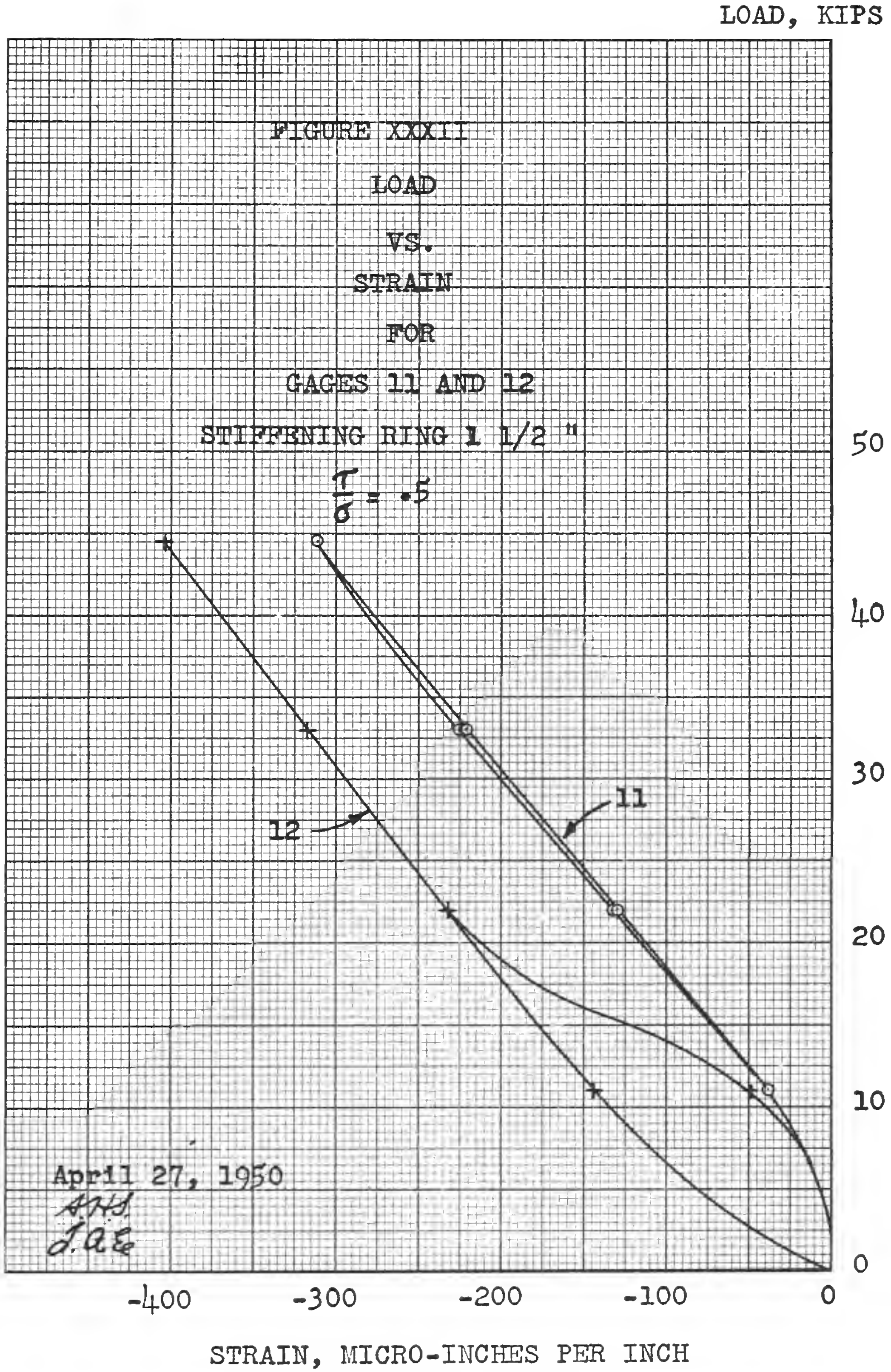


Figure XXXIII

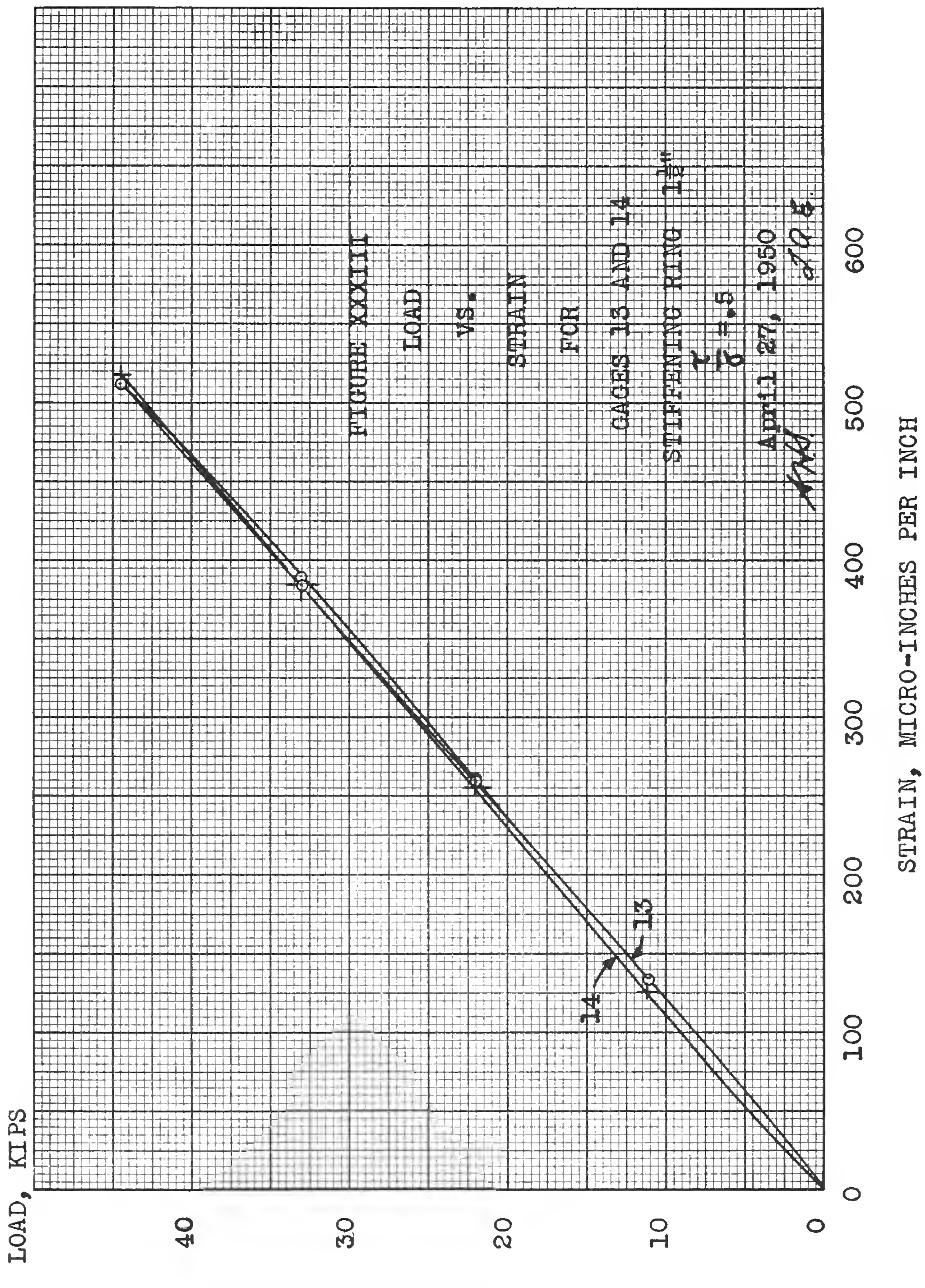


Figure XXXIV

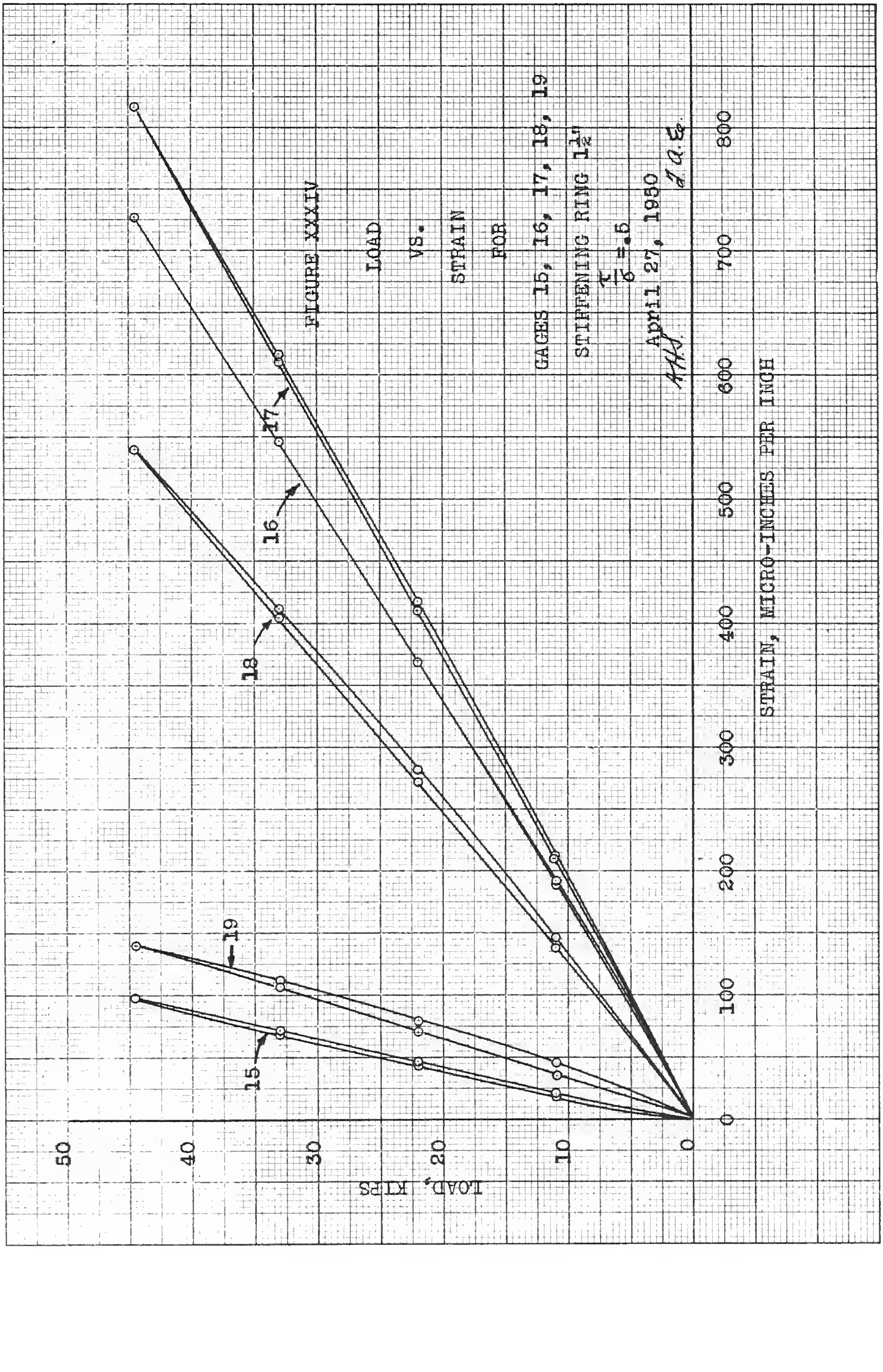


Figure XXXV

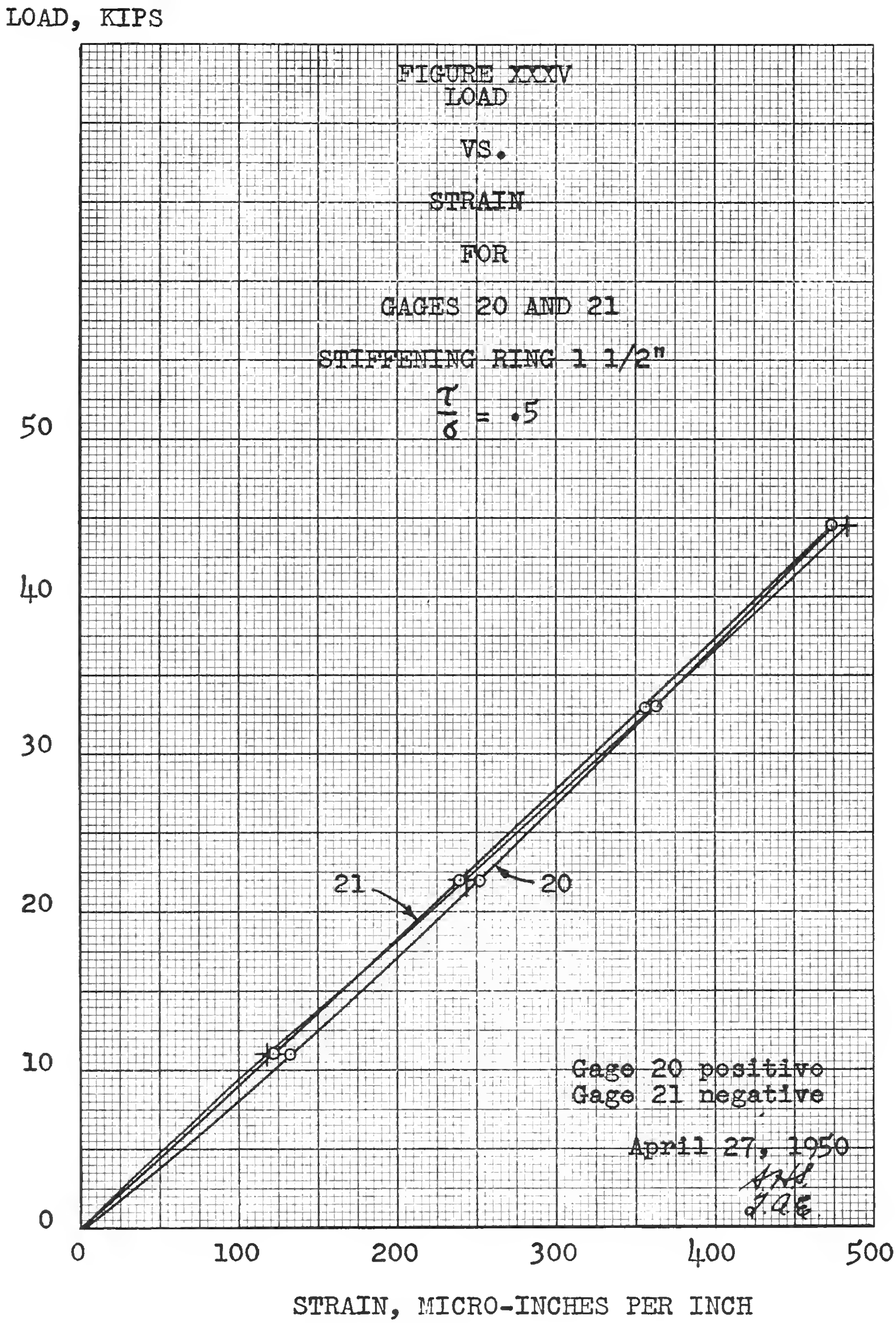

LOAD, KIPS
FIGURE XXXV
LOAD
VS.
STRAIN
FOR
GAGES 20 AND 21
STIFFENING RING 1 1/2"
$\frac{\tau}{\sigma} = .5$
50
40
30
20
10
0
21
20
Gage 20 positive
Gage 21 negative
April 27, 1950
0
100
200
300
400
500
STRAIN, MICRO-INCHES PER INCH

Figure XXXVI

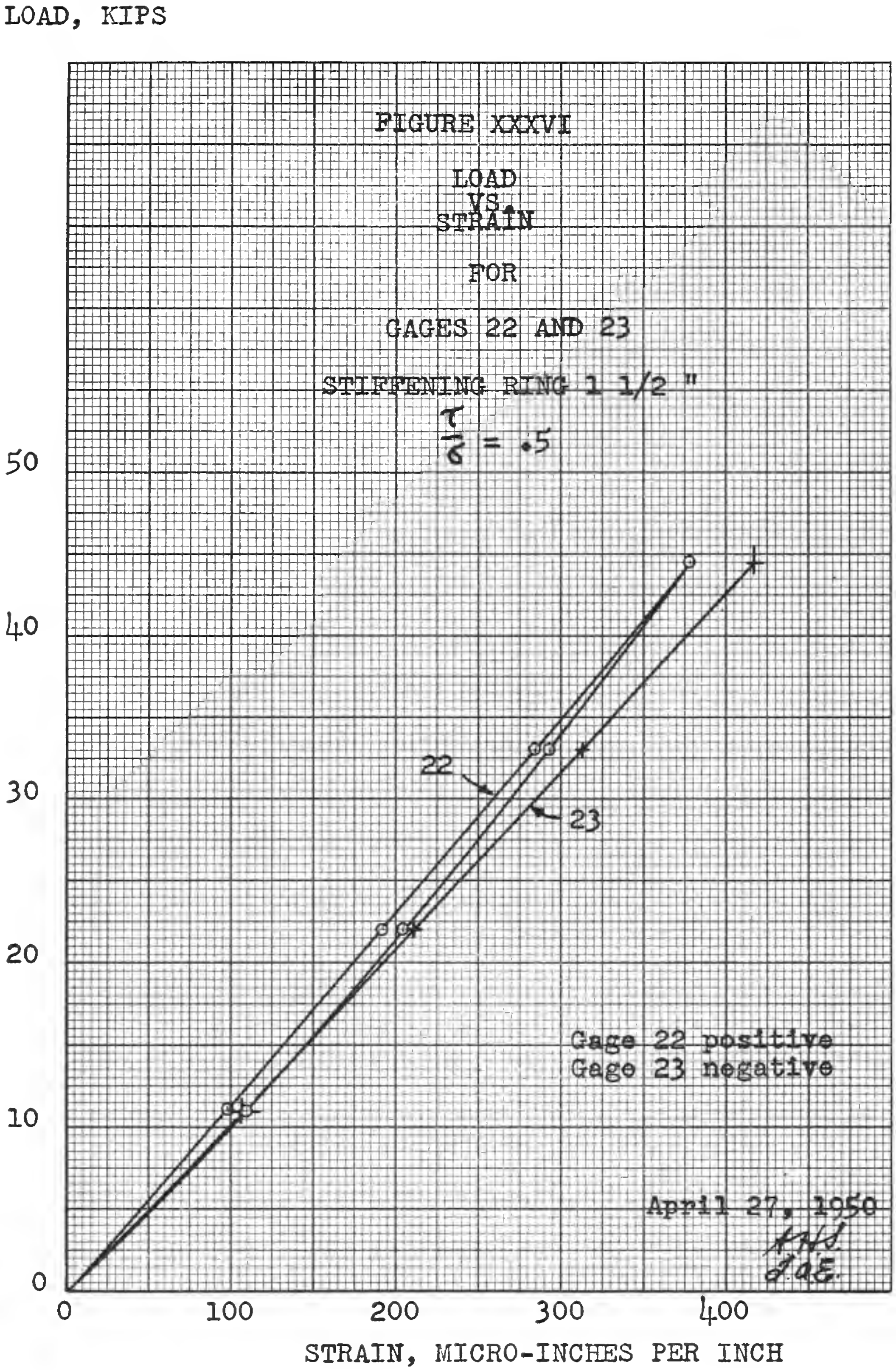


Figure XXXVII

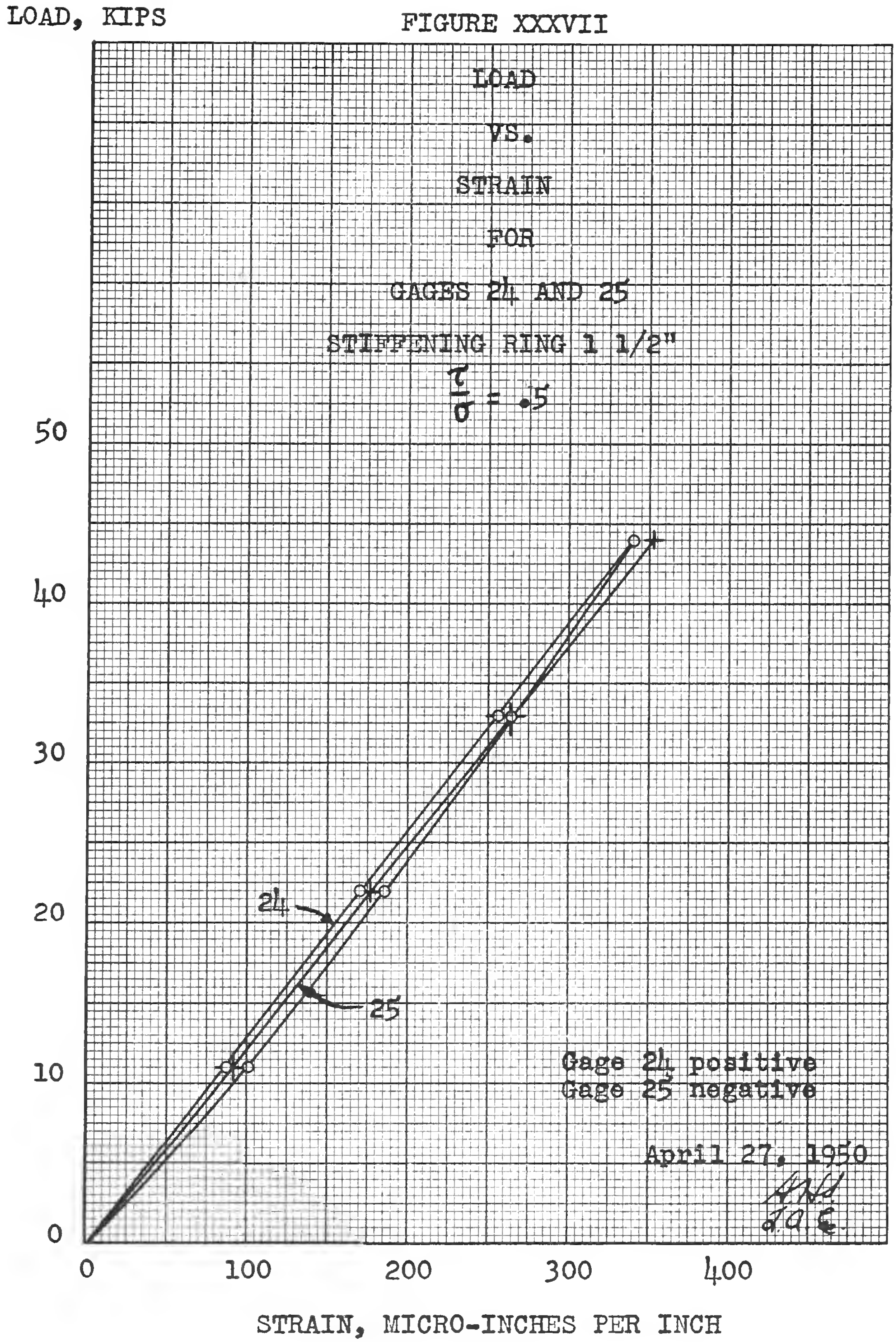


Figure XXXVIII

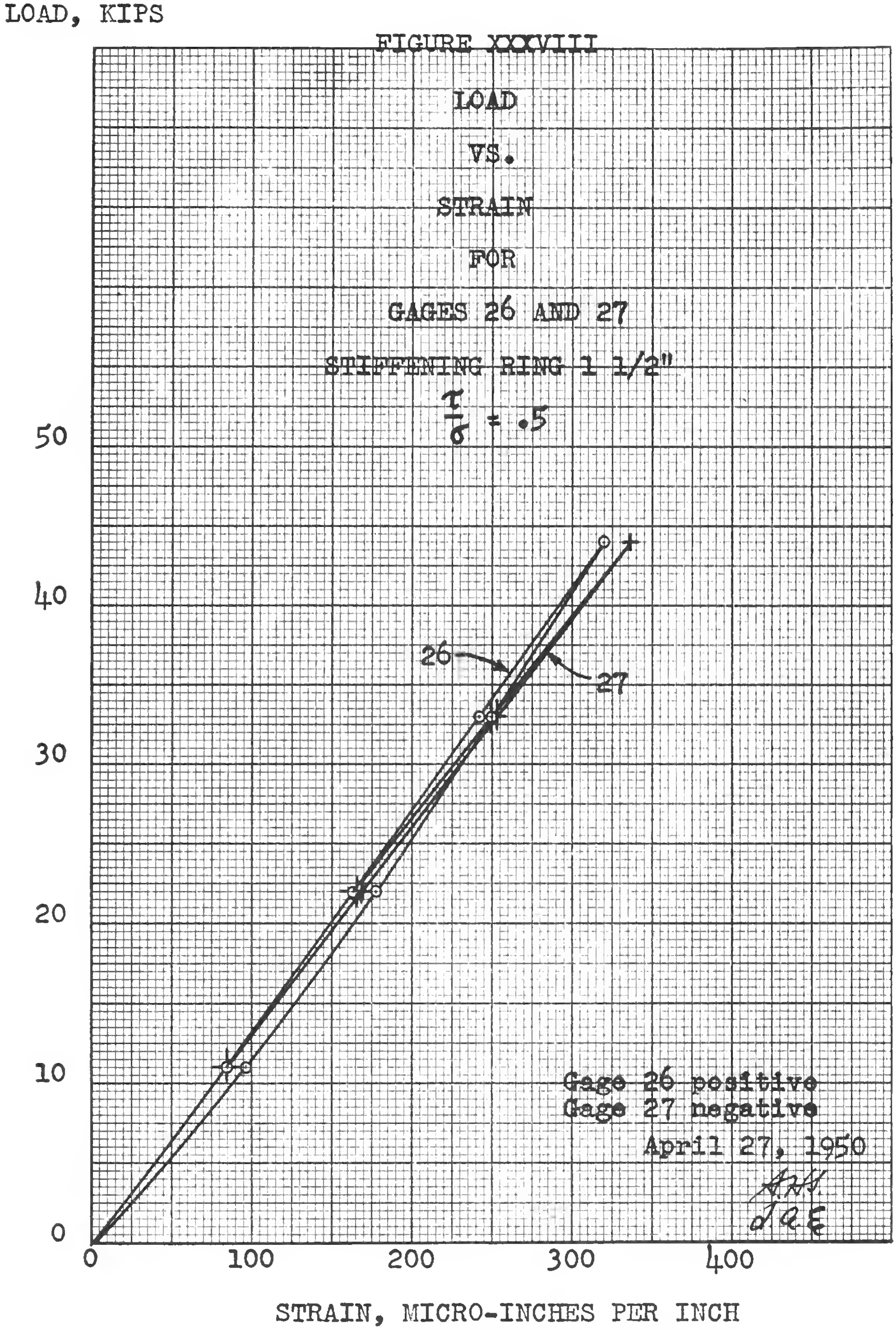
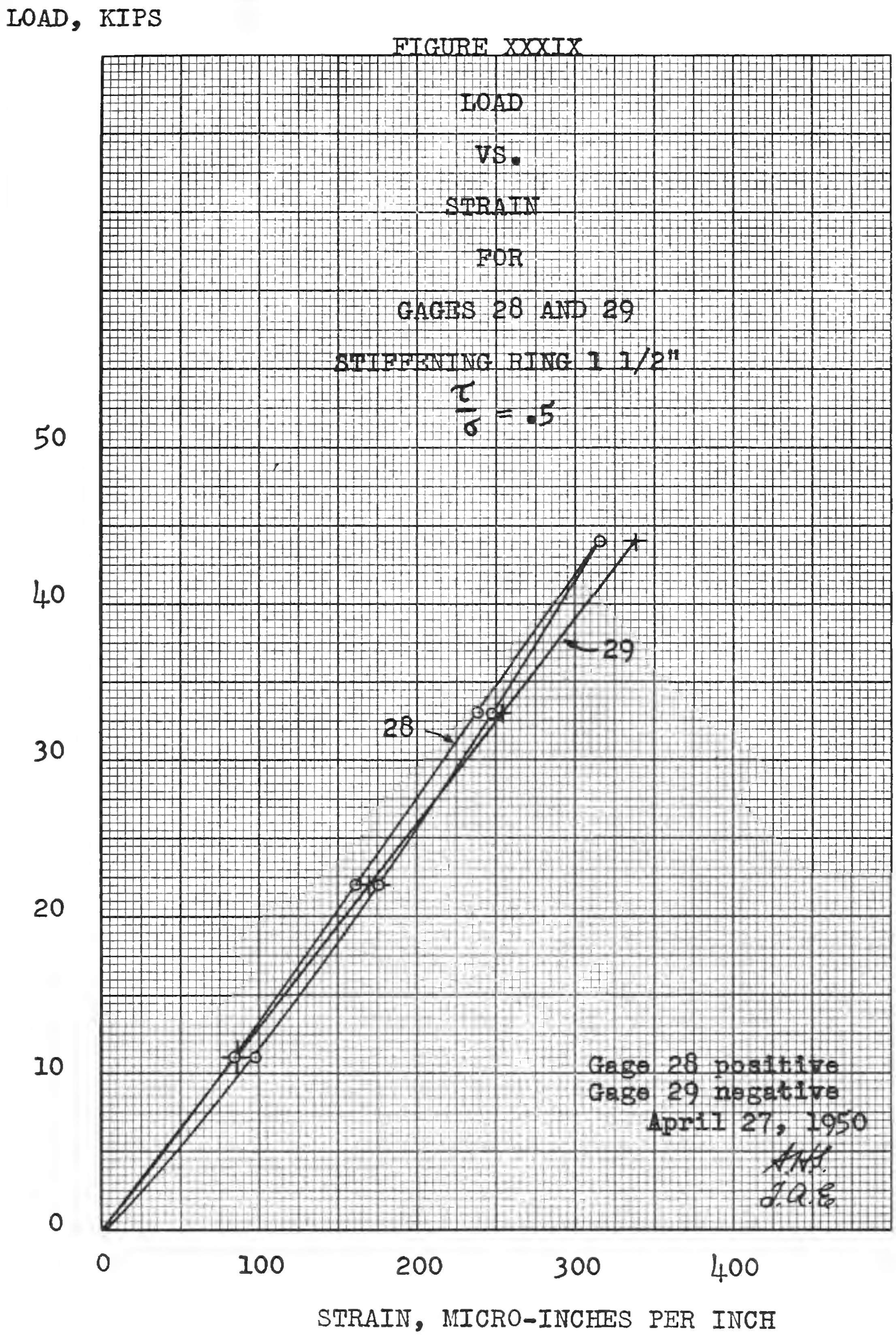


Figure XXXIX



TENSILE TEST OF MATERIAL

Two flat plate test specimens were prepared in accordance with the specifications of the A. S. T. M., one from an excess portion of the original beam, the other from material corresponding to that used in the flat bar stiffening ring. These were tested in a 60,000 pound Baldwin-Southwork hydraulic testing machine. Huggenburger Tensometers were attached to the specimens and readings of strain were made at each load. From the load vs. strain plot of each specimen, Figures XL and XLI, the modulus of elasticity and the approximate yield point were obtained.

The multiplication ratios for the Tensometers were as follows:

No. 69	325
No. 71	330

TABLE XIII

TENSILE TEST SPECIMEN CUT FROM STEEL BEAM

Load, Lbs.	Huggenburger Readings		Avg. Reading	Elongation $x10^{+3}$
	H - 69	H - 71		
1000	.02	.03	.025	.077
2000	.05	.065	.0575	.176
3000	.08	.10	.090	.275
4000	.12	.125	.1225	.375
5000	.15	.155	.1525	.466
6000	.175	.180	.1775	.543
7000	.21	.21	.21	.642
8000	.24	.24	.24	.735
9000	.26	.26	.26	.795
10000	.30	.30	.30	.9175
12000	.355	.355	.355	1.085
14000	.425	.415	.420	1.285
16000	.48	.47	.475	1.453
17000	.52	.50	.51	1.560
17700	.55	.52	.535	1.637
17500	.55	.51	.53	1.620
17200	1.20	1.20	1.20	3.67

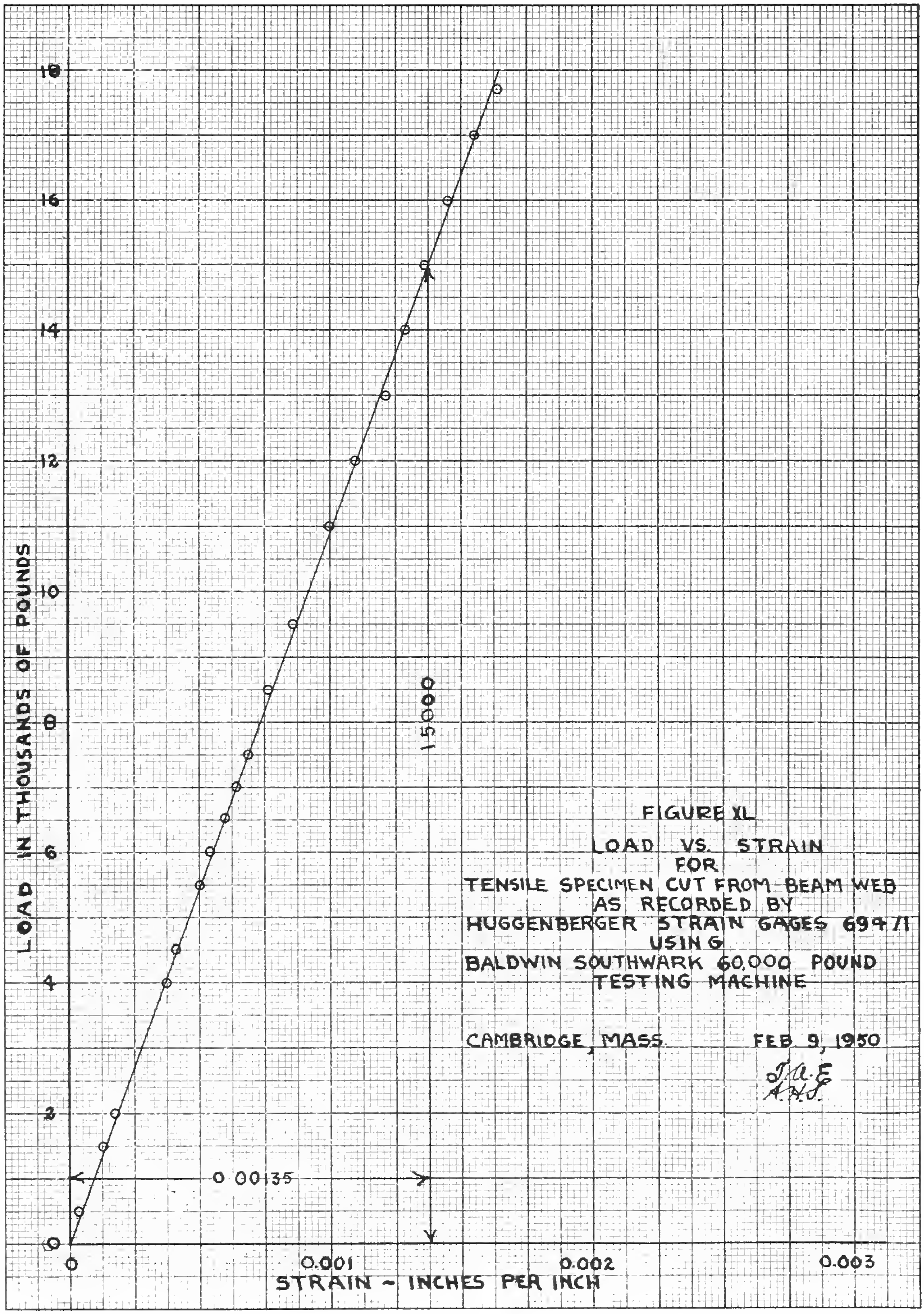
Area of cross section 0.361 sq. in.

Approximate yield load 17,700 Lbs.

Approximate yield point 49,000 psi.

Modulus of Elasticity 30.3×10^6 psi.

Figure XL



18
16
14
12
10
8
6
4
2
0
LOAD IN THOUSANDS OF POUNDS
0
0.001
0.002
0.003
STRAIN ~ INCHES PER INCH
0.00135
15000
FIGURE XL
LOAD VS. STRAIN
FOR
TENSILE SPECIMEN CUT FROM BEAM WEB
AS RECORDED BY
HUGGENBERGER STRAIN GAGES 694/1
USING
BALDWIN SOUTHWARK 60,000 POUND
TESTING MACHINE
CAMBRIDGE, MASS.
FEB. 9, 1950

TABLE XIV

TENSILE TEST SPECIMEN

CUT FROM FLAT BAR

Load,	Huggenburger Readings H - 69	Huggenburger Readings H - 71	Average Readings	Elongation $x10^3$
0	-.10	-.10	-.10	-.0306
1000	-.08	-.12	-.09	-.0275
2000	-.05	-.10	-.08	-.0245
3000	-.03	-.07	-.05	-.0153
4000	-.00	-.05	-.025	-.0076
5000	.02	-.04	-.02	-.0061
6000	.05	.00	+.025	+.0076
7000	.07	.01	.04	.0122
8000	.10	.045	.0725	.0222
9000	.145	.05	.0825	.0252
10000	.150	.08	.115	.0352
12000	.19	.145	.167	.0512
14000	.23	.180	.205	.0670
16000	.275	.230	.252	.0772
18000	.33	.27	.30	.0917
19000	.35	.280	.315	.0963

Area of cross section .500 sq. in.

Approximate yield load 19000 Lbs.

Approximate yield point 38,000 psi.

Modulus of Elasticity 28.28×10^6 psi.

Figure XLI

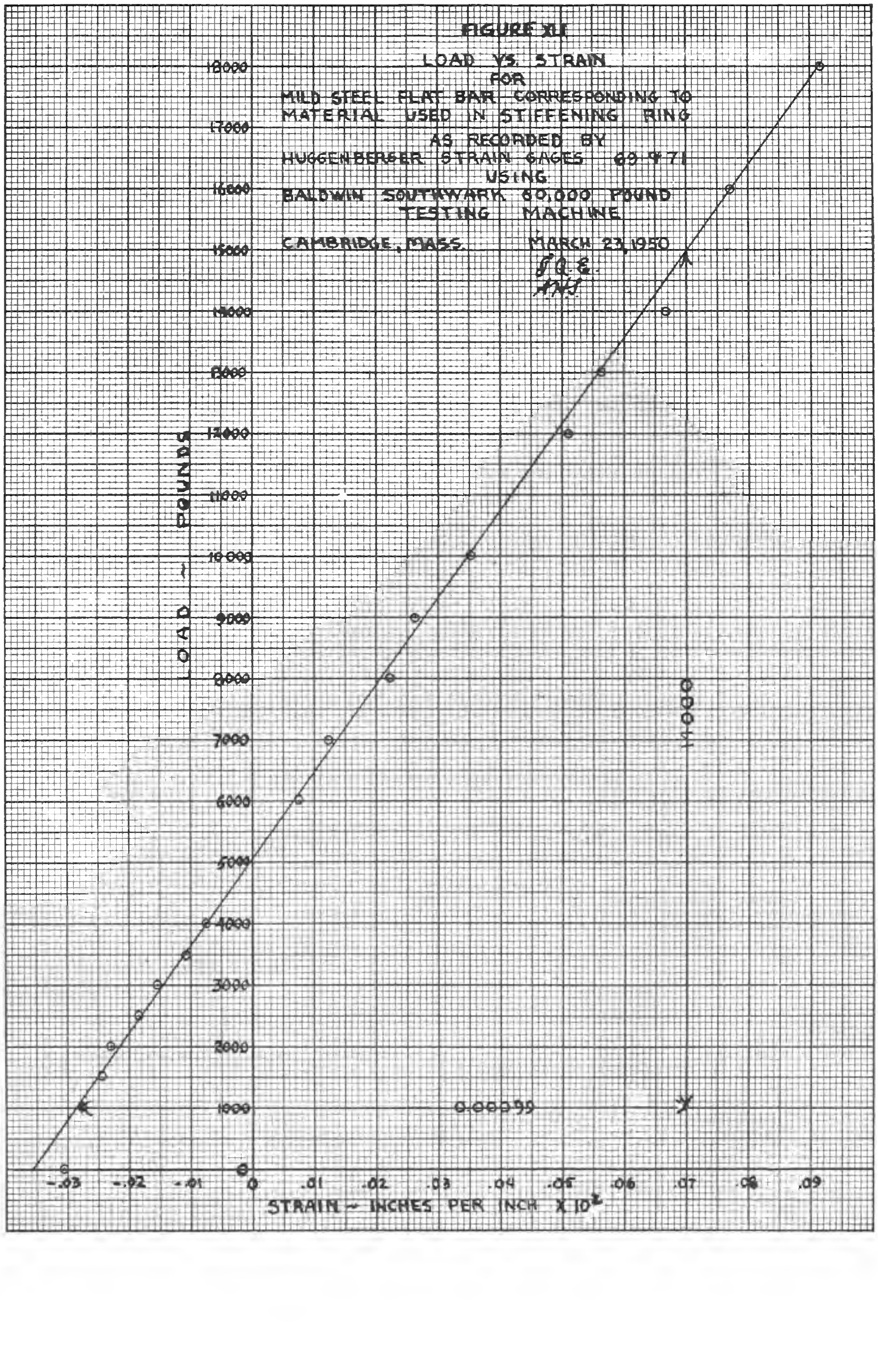
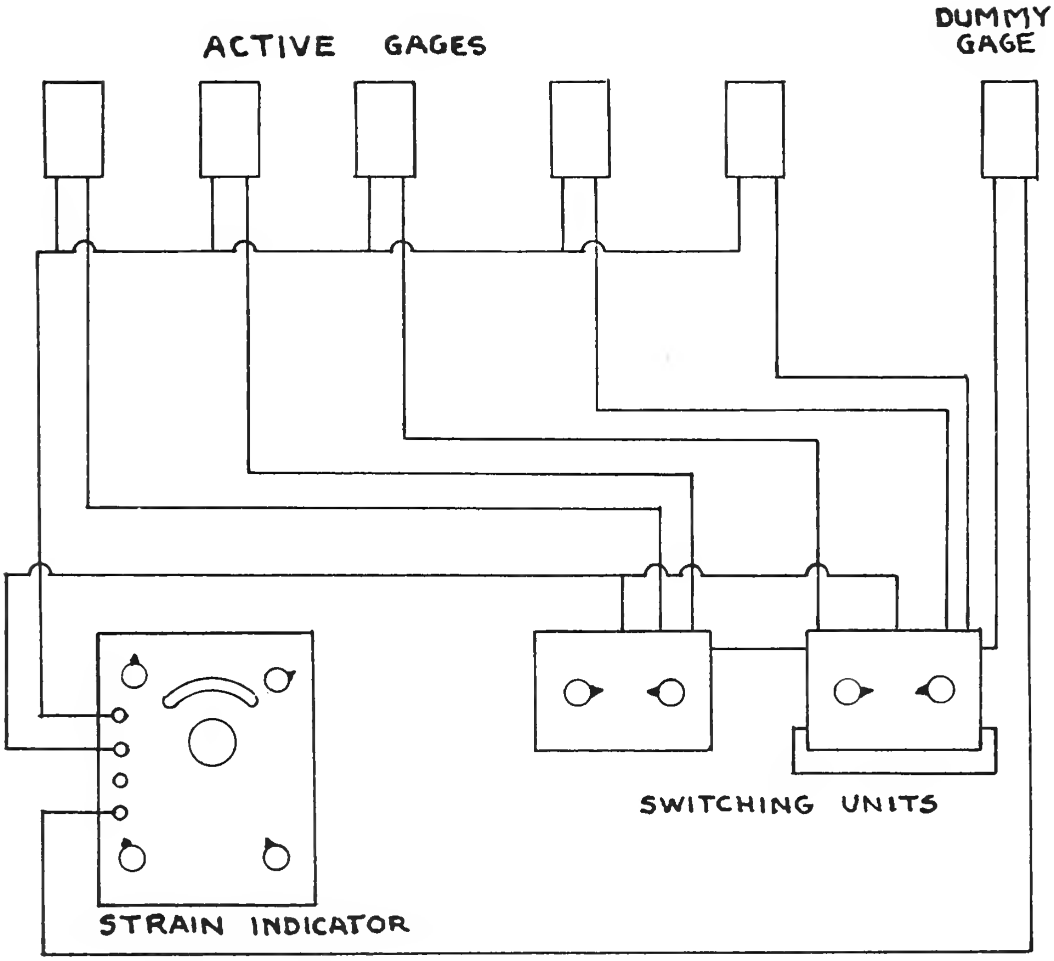


FIGURE XLI
LOAD VS. STRAIN
FOR
MILD STEEL FLAT BAR CORRESPONDING TO
MATERIAL USED IN STIFFENING RING
AS RECORDED BY
HUGGENBERGER STRAIN GAGES 69-71
USING
BALDWIN SOUTHWARK 60,000 POUND
TESTING MACHINE
CAMBRIDGE, MASS. MARCH 23, 1950
LOAD ~ POUNDS
STRAIN ~ INCHES PER INCH X 10²
0.00095
14,000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-.03
-.02
-.01
0
.01
.02
.03
.04
.05
.06
.07
.08
.09

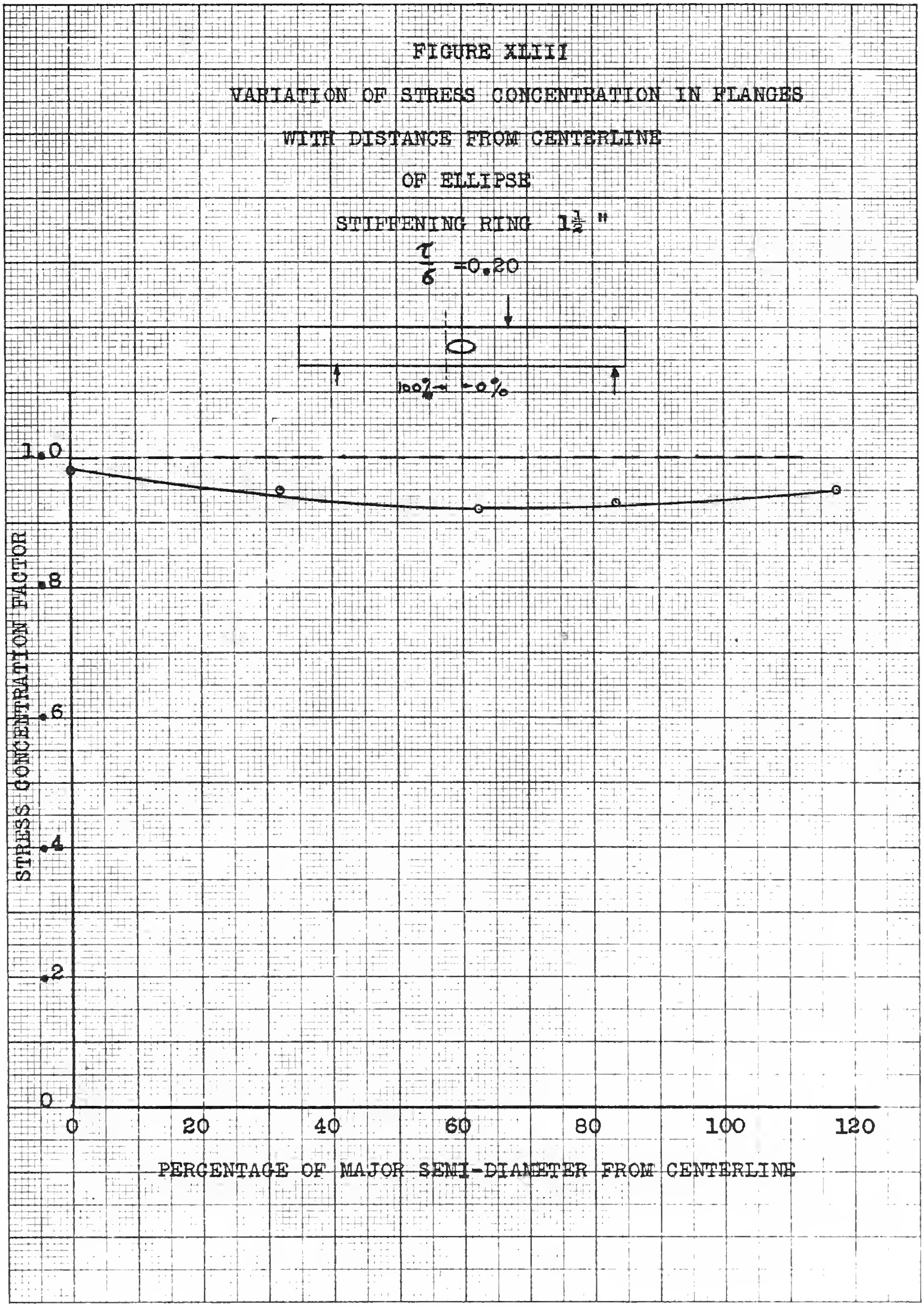
FIGURE XLII



WIRING DIAGRAM
FOR
STRAIN GAGES AND INSTRUMENTS

APRIL 29, 1950
J. A. E. A.H.S.

Figure XLIII



APPENDIX E

BIBLIOGRAPHY

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Thesis 12869
E26 Efird
Stress concentration in a beam with a reinforced elliptical discontinuity.